DAC-63264

RANKING AND SELECTION OF INSULATION SYSTEMS FOR MNV APPLICATION

Special Report No. 1

Investigation of High-Performance Insulation Application Problems

Prepared under Contract No. NAS8-21400
by Advance Aero/Thermodynamics and
Nuclear Effects Department
McDonnell Douglas Astronautics Company – Western Division
Santa Monica, California
for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

This is a special report on the program entitled, "Investigation of High-Performance Insulation Application Problems." The work is being performed for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama, under Contract NAS8-21400. This report covers the ranking and selection of the three most promising insulation systems from among the seven candidates evaluated in the study.

The study effort described herein was accomplished under the direction of the following Insulation Study personnel:

G. O. Fredrickson, Project Manager
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Section 1
INTRODUCTION AND SUMMARY

1.1 STUDY OBJECTIVES

The first major objective in the contract, High Performance Insulation Applications, NAS8-21400, is the selection of the three most promising insulation systems for Modular Nuclear Vehicle (MNV) application from among the study candidate systems. These candidates (15-gage mylar) are:

1. Double aluminized mylar (DAM) with Tissuglas spacer
2. DAM with foam spacer
3. DAM with Dexiglas spacer
4. DAM with nylon net spacer
5. Embossed double aluminized mylar (DAME) with Tissuglas spacer
6. Embossed single aluminized mylar (SAME)
7. Superfloc.

The objective was achieved. The three selected systems and the study effort required to accomplish selection are described in this report.

1.2 SUMMARY OF STUDY

1.2.1 Minimum Practical Density of Insulation Systems

To accomplish a selection it is necessary to rank all systems on the basis of associated MNV LH_2 thermal protection weight penalty and insulation system fabricability. But the weight and fabricability parameters can be uniquely assessed only if the insulation system's minimum practical (repeatable) layer density (MPD) is known. Upon commencement of the study, generally agreed upon values of MPD for the candidate systems were not available. Reported values were based upon shop experience, a relatively intangible parameter, with results varying from shop to shop.

Because thermal performance of the insulation is a strong function of layer density, a ranking and selection may be incorrect if improper insulation density values are utilized. Therefore, a totally new, more scientific, approach which defines minimum practical layer density was developed as the first step toward material selections. This method will produce repeatable results from shop to shop.

A measurements study was first accomplished to determine quantitatively the parameters influencing minimum practical density and their relationship to one another. The thickness of actual stacks (five) of the seven insulation systems were measured and found to vary widely, corresponding to a statistical distribution of thickness. Consequently, for any thickness (density) selected for design, some layups can be expected which are thicker (less dense) and others thinner than any selected design thickness. To achieve repeatability the thicker layups must be reduced to a selected design thickness. Those too thin must be rejected. A statistical analysis based on the measurement data was accomplished to define this relationship between design thickness and the number of layups which can be expected to be too thin. Thickness was also found to be a function of the number of sheets stacked and the time after stacking; a settling phenomenon.

The minimum practical density parameter was, therefore, found to be a function of the number of sheets stacked, degree of settling expected and the desired manufacturing acceptance (rejection) rate of initial panel layups. A formalized procedure was developed to relate these parameters to define the minimum practical design density. This methodology was utilized, along with the quantitative data acquired through measurement, to define minimum practical densities for MNV application and subsequent thermal and fabricability ranking.

A new device, suitable for production, was developed to provide accurate thickness measurements of the above insulation stacks. Essentially, it utilizes modified standard height gages electrically connected in series to the insulation. Gage contact completes the circuit indicating the measurement value.

1.2.2 Verification of Fabricability to Minimum Practical Density

Tooling was developed and built which would provide repeatable manufacture of minimum practical density insulation panels. One 4- by 5-foot panel of each candidate insulation material was fabricated to verify the shop's ability to build panels of the design minimum practical density. Verification was obtained through measurement of completed panel thickness. Panels were assembled with stud and button fasteners which control the panel thickness (density) to the design value. Compression of the insulation due to punching for stud insertion was also parametrically evaluated. No appreciable effect was measured.

1.2.3 Thermal Ranking

Ranking of the seven systems was accomplished on the basis of the weight penalty (insulation and boiloff) associated with use of the optimum amount of each insulation on the baseline MNV for the baseline mission.

Current preferred MNV configurations were reviewed and a baseline selected to provide a basis for analyses, with the concurrence of NASA/MSFC. It is a thermos-bottle configuration, 396 inches in diameter, $\sqrt{2}$ elliptical domes, with a propellant capacity of 250,000 pounds of LH_2. Missions currently considered were also evaluated. The baseline selected is the same used in previous MSFC MNV insulation studies (Reference 1): a 300-day Mars trip.

The optimum amount of each candidate insulation material required for the MNV was then determined parametrically as a function of insulation density (thickness). The minimum practical density relationships, above, were applied to define the required MNV insulation thickness and design density. Thus, a thermal ranking resulted. For a 75 percent panel manufacturing acceptance rate, the minimum believed realistic, the resulting ranking was found to be: Superfloc; DAM/Tissuglas; DAME/Tissuglas; DAM/Dexiglas; DAM/nylon net; SAME; and DAM/foam. Minimum practical densities were found to be somewhat higher than reported in the literature.

1.2.4 Fabricability Ranking

An extensive fabricability ranking effort was accomplished to:

1. Develop a ranking methodology based on quantitative factors rather than the intangible shop experience parameter generally used to date.
2. Provide quantitative data on the study materials for immediate ranking and to provide a basis for comparison with additional systems which may be developed in the future.

The basis of the fabricability ranking was data obtained in the actual fabrication of a panel of each insulation system. These panels were built to the MNV density (thickness) requirements defined during the thermal ranking work.

Data on fabrication costs, panel uniformity, materials costs, and material problems were recorded. Ranking was accomplished on the basis of: fabrication costs, predictability, susceptability to damage, and material costs. Actual observed fabrication times were corrected for a learning curve prior to using the data for ranking. The resulting fabricability ranking was found to be: Superfloc; DAM/nylon net; DAM/Tissuglas; DAM/foam, DAM/Dexiglas, DAME/Tissuglas; and SAME.

1.2.5 Selection of Systems

Thermal and fabricability rankings were finally integrated since both must be simultaneously considered in the selection process. Development of quantitative integration criteria was attempted and a criterion defined; cost per pound of vehicle payload. However, the necessary vehicle parameters were felt to be currently in too great a state of flux to quantitize the criteria. Ranking and selection were accomplished by modifying the thermal ranking only if the material rated low on the basis of fabricability. The resulting three most promising systems are: Superfloc, DAM/Tissuglas and DAM/nylon net.

1.3 REPORT SUMMARY

Details of the work summarized above, are discussed in the following sections. Section 2 defines the minimum practical density of insulation systems. Insulation requirements for the baseline MNV configuration and mission along with the thermal ranking will be found in Section 3. Panel fabrication and fabricability ranking work is presented in Section 4. The Section 5 discusses the integration of the thermal and fabricability rankings and the resulting selection of the three most promising systems.

The detailed insulation thickness measurements and tooling error measurements, taken during the study are listed in Appendix A. A numerical example of a minimum practical density design calculation will be found in Appendix B. Notes on materials fabricability, previously not reported, are summarized in Appendix C.

Section 2
MINIMUM PRACTICAL LAYER DENSITY OF INSULATION SYSTEMS

Minimum practical layer density is a phrase repeatedly encountered in discussions and analyses of high-performance insulation (HPI) systems. It is the most important parameter because, for all HPI systems, maximum thermal performance is achieved with minimum layer density. For any given system, the numerical value of this parameter has been steeped in controversy.

Shop experience has been the usual method of determining minimum practical layer density. But, the results of one shop's experience have not always been repeated in another. Therefore, the analyst has been faced with a dilemma. Because of the strong influence of layer density on thermal performance, vehicle insulation requirements and comparison of candidate insulations could not be determined with assurance.

It was necessary to resolve this problem to accomplish a realistic ranking of Modular Nuclear Vehicle (MNV) insulation candidates. This was accomplished by developing a consistently repeatable method of defining and fabricating minimum practical layer density insulation panels.

The method developed and used as a basis for MNV insulation ranking is described below. Discussed are the influencing parameters, relationship of these parameters to insulation layer density, experimental evaluation of insulation thickness relationships, statistical prediction of system minimum layer density, and methodology for application to vehicle design.

This material pertains to the seven candidate insulation systems (15-gage mylar) evaluated: double aluminized mylar with Tissuglas, Dexiglas, nylon net and closed-cell foam spacers; Superfloc; single aluminized embossed mylar; and double aluminized embossed mylar with Tissuglas spacer.

However, the evaluation methodology is valid for use with any HPI system which may be of interest in the future.

2.1 RELATIONSHIP OF INFLUENCING PARAMETERS

2.1.1 Sidewall Panels

For a sidewall panel the minimum layer density which could be repeatably achieved would be that resulting from a vertical fabrication; that is, hanging each insulation sheet from an attachment with some provision for positive spacing of the sheets from one another. This fabrication approach was rejected as impractical and excessively costly, particularly for the very long panels associated with the MNV. It is far more likely that panels would be fabricated and stored (for periods of a year or so) in a horizontal position. Therefore, it was concluded that the initial stack layer density on horizontal tooling is a fundamental parameter defining the system minimum practical layer density. However, observation of the thickness of insulation panels after layup of an identical number of individual sheets into stacks yielded a significant result; all are different.

Analysis of the manufacturing and installation sequence showed that there are only two other potential operations which can lead to compression, hence, increased minimum layer density. These are punching for the stud-button attachments used to hold the assembled panel together and possible technician compression of panels during installation. It is believed that the latter problem can be circumvented through the use of handling jigs.

The extended storage requirement introduces another parameter because layer density increases due to settling. This phenomenon (observed during the study) results in the insulation stack layer density increasing with time without outside influence.

To achieve predictability, layer density after installation must be repeatable from panel to panel and from manufacturer to manufacturer. This criterion requires that all panels be of a uniform standard thickness and that random "fluffing" between attachments be restrained. Therefore, it was concluded that sidewall panel minimum layer density is defined by the initial stack layer density on horizontal tooling modified by:

1. Compression due to punching operations.
2. Layer density increases due to settling.

This initial stack layer density is that associated with the number of sheets in one sidewall panel, not necessarily the total number of sheets required for sidewall application. Current designs recommend that three or more panels one on top of the other be used to make up the total required insulation thickness.

2.1.2 Dome Panels

The MNV domes will probably be elliptical. Hence, near the center the insulation will be nearly horizontal, a situation similar to the side panel on horizontal tooling.

However, here the interior panel will be compressed from the weight of the outer panels. Therefore, a minimum layer density, as installed, will be greater than a similar sidewall panel. In addition, compression may be introduced (increasing layer density) from the weight of the insulation pulling the sheets down onto the curved surface as the sheet follows the dome curvature. Thus, the as installed, minimum practical, insulation layer density for the vehicle is that associated with a sidewall panel, not the dome.

2.1.3 Distribution of Initial Layup Thicknesses

As noted above, the primary parameter influencing minimum practical layer density is initial stack thickness and this varies from stack to stack. A distribution of thicknesses can be expected if a number of stacks are measured. This is depicted in Figure 2-1. This curve shows that for any layer density (thickness) selected some initial layups will be too thick and others too thin. If repeatable thermal performance (manufacture) is to be achieved, a design layer density must be first selected. Then layups which are too thick must be compressed to the design thickness before assembly.

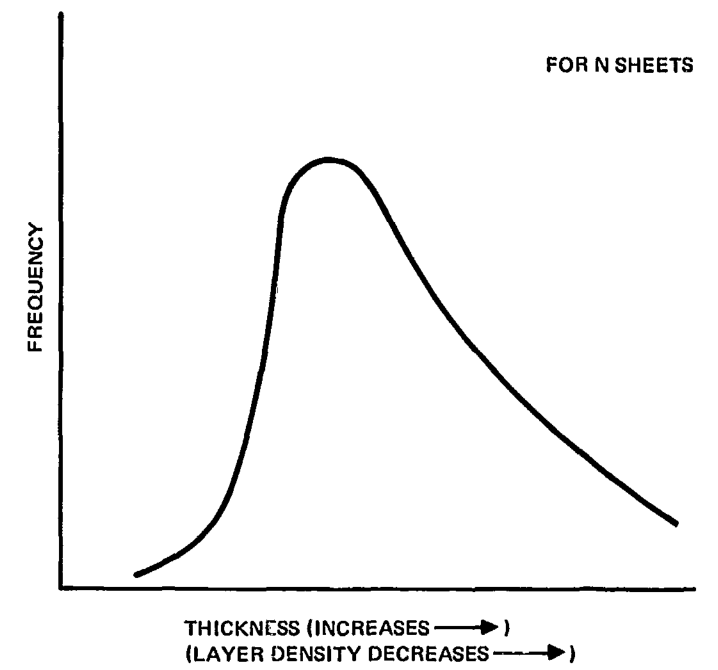


Figure 2-1. Distribution of Insulation Stack Initial Thickness

Layups which are too thin must be rejected. Studs with length equal to the design thickness can then be inserted to hold the assembly together at the design thickness. Note that increasing the design layer density increases the number of acceptable panel layups, and conversely. The fundamental problem to be resolved, and the one attacked in the study, is how to select this design thickness.

2.1.4 Parametric Relationship of Variables and Design Methodology

The parametric relationship of the variables defining minimum practical layer density follows directly from Figure 2-1 and is shown in Figure 2-2. The figure shows that layer density is a function of manufacturing acceptance (rejection) rate of panel layups, the number of sheets in a panel, compression induced during manufacture, and the degree of settling expected.

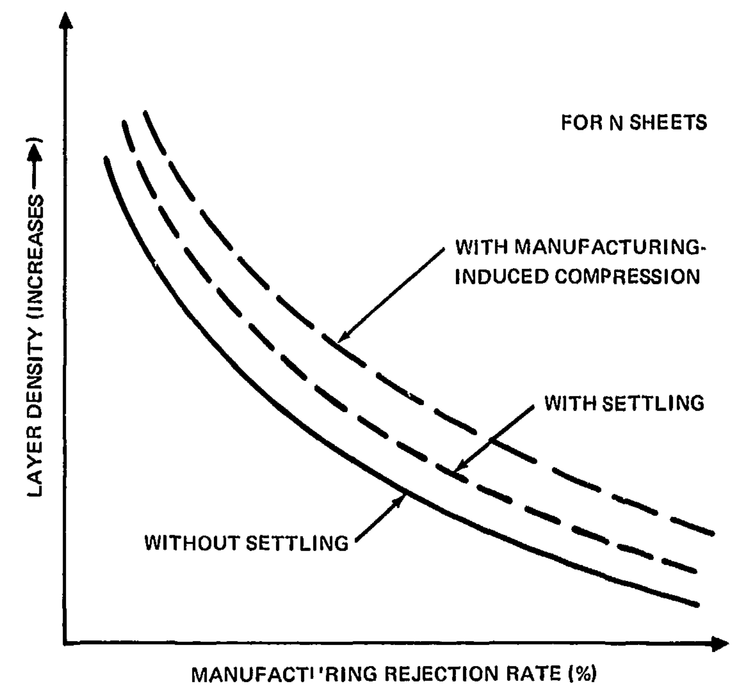


Figure 2-2. Parametric Minimum Density Relationships

The basic curve shown represents the minimum practical repeatable layer density when only the variation in stack thickness in initial layup (one specific number of sheets in stack) is considered. The effect of settling, manufacturing compression, and any other compressions is to increase this value. Because minimum practical layer density is a function of the number of sheets in the stack, another set of similar curves is obtained for each number of sheets considered. A family of curves results.

Note that minimum practical layer density is one unique number only when a manufacturing acceptance rate and the number of sheets used in panel layup is specified. Hence, minimum practical layer density is a direct function of the number of sheets required for the particular vehicle application. Also, a tradeoff is involved. Increased panel thermal performance (decreased minimum practical layer density) can be achieved only by increasing manufacturing costs and complexity due to the necessary increased rejection rate.

To apply the relationship denoted in Figure 2-2 to a design determination of minimum practical layer density the following are required:

1. The numerical relationship between layer density and manufacturing acceptance rate for stacks with a number of sheets bounding the range of interest.
2. · numerical measure of the degree of settling experienced.
3. The degree of compression induced by manufacture.
4. The number of sheets required for the vehicle installation.

Items 1, 2, and 3 were experimentally determined for the seven systems and data are presented in Subsection 2.4. In item 3 punching-induced compression was found to be negligible with the fabrication method developed in the study and is described in Section 4.

Note that an iteration technique is required. A density must be selected and the vehicle insulation thickness required computed from a mission analysis. Selecting a manufacturing acceptance rate, the minimum practical layer density which can be achieved with the computed thickness requirement is determined from the Figure 2-2 relationship. This new layer density, which in all probability is different from the initial assumption, is used to compute a new thickness required for the mission. This iteration must be continued until the possible minimum practical density corresponds to that used for definition of vehicle requirements. This procedure is further numerically described and used in Section 3 for computation of the study baseline MNV insulation requirements.

2.2 MEASUREMENT OF INSULATION STACK (PANEL) THICKNESSES

The numerical relationship of layer density to manufacturing acceptance rate was determined statistically. This was accomplished by inferring the expected thickness characteristics of all possible panel layups of a given number of sheets from the thickness distribution obtained from statistical samples.

2.2.1 Insulation Materials Evaluated

The candidate systems evaluated were:

1. Embossed single aluminized mylar (SAME)
2. Embossed double aluminized mylar (DAME)--Tissuglas spacer (DAME/Tissuglas)
3. Double aluminized mylar (DAM)--Dexiglas spacer (DAM/Dexiglas)
4. Closed-cell foam spacer - DAM (DAM/foam)
5. Nylon net spacer - DAM (DAM/nylon net)
6. Superfloc
7. Tissuglas spacer - DAM (DAM/Tissuglas).

The properties of these materials are presented in Table 2-1. Note that these represent 15-gage material. Mylar reflector sheets, 0.25-mil thick, were originally considered for use. However, a typical MNV insulation system is expected to be approximately 500 pounds lighter if 0.15-mil material is used. Although specific heat transfer data are not available to fully assess any improvements, performance should be at least equal to that of the 0.25-mil material. Previous work (Reference 1) suggested that embossed materials may exhibit a more uniform density than the presently favored crinkled type. Therefore, with the concurrence of NASA-MSFC, 0.15-mil materials, embossed where required, were selected.

2.2.2 Statistical Sample Panels Evaluated

The statistical sample used for the thickness distribution measurements consisted of five panel layups of each system, with nine thickness measurements on each sample. This provided a theoretical sample size of 41 (see Subsection 2.3.1), considered adequate for standard statistical processing. Because distribution curves vary with the number of sheets in a panel, a statistical sample was obtained for each of three different numbers of sheets for each system. The numbers used in this study, shown in Table 2-2, were based on preliminary computations of typical MNV requirements. The values roughly represent a number of sheets which is less than, equal to, and more than one-third or one-fourth the total sheets needed for the stage configuration presented in Reference 1. Computation details can be found in Reference 2.

Table 2-1

CANDIDATE MATERIAL PROPERTIES, WEIGHTS, EMISSIVITIES, AND THICKNESS

Material	Weight (lb/ft^2-Sheet)	Emissivity	Thickness (mils)	System	Weight (lb/ft^2-Layer)
Dexiglas	0.0032	–	2.7 to 2.8	DAM/Dexiglas	0.0044
Tissuglas	0.0010	–	0.8 to 0.9	DAM/Tissuglas	0.0022
Nylon net	0.0028	–	8.8	DAM/Nylon net	0.0040
Foam	0.0062	–	31.0	DAM/Foam	0.0074
SAME	0.0012	0.03, 0.40	0.14	SAME	0.0012
DAME	0.0012	0.03	0.14	DAME/Tissuglas	0.0022
DAM	0.0012	0.03	0.15		
Superfloc	0.0016	0.03	0.14 (No Floc)	Superfloc	0.0016

Table 2-2

NUMBER OF SHEETS IN STATISTICAL SAMPLE

System	MDAC-WD 4 - Panel	MDAC-WD 3 - Panel	Selected Statistical Sample Panels
SAME	20	26	15-25-35
DAM/Nylon net	20	25	20-30-40
Superfloc	10	12	10-15-20
DAM/Dexiglas	25	32	20-26-32
DAM/Tissuglas	18	24	20-30-40
DAME/Tissuglas	25	33	15-25-35
DAM/Foam	20	20	17-20-23

The panels measured were approximately 2 by 4 feet. This size was selected to permit examination over a typical full width segment without including any edge distortion.

2.2.3 Panel Measurement Procedure

Panels were first stacked to the lowest number of sheets and the thickness measured at the nine locations shown in Figure 2-3. Additional sheets were then added to the panel to the next total number of sheets and the thickness measured at the same locations. The panel was measured a third time after all sheets had been added. The panel was then removed from the measuring surface and stored on a work bench. The stack and measuring procedure was repeated for four more panels of each system. After measurements on the fifth panel were completed, the other four panels were added one at a time. The thickness of the multi-panel stack was measured after each panel was added, at the same locations. The five panels were then randomly restacked and remeasured, in a repeat procedure, to provide data on a sample of ten panels. Randomness was simulated with a cut and shuffle technique. All data are tabulated in Appendix A.

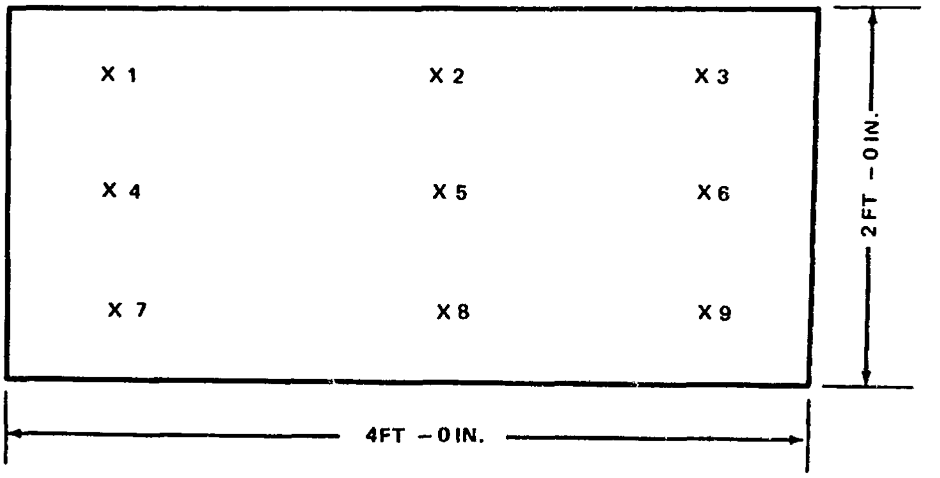


Figure 2-3. Panel Thickness Measurement Locations

All measurements were made on a surface table using a modified height gage as shown in Figure 2-4. The gage was assembled from two standard gages connected with a steel bar supporting a movable depth micrometer. Thickness was recorded as the difference between depth gage reading at point of contact with an insulation panel on the table and the reference height of the supporting bar above the table. The total system, table, height gages, bar, and depth gage were flat within 0.006 inch. The beam deflection profile of the system is presented in Appendix A.

A measurement automation technique was developed to save time and increase accuracy. The depth gage probe and the aluminized insulation surface were connected to a battery and an ohmeter. Probe contact with the top surface of the insulation completed the electrical circuit and was indicated on an ohmeter. Pieces of paper served as insulators between the base of each height gage and the steel table. The method proved to be very successful in this application and it is felt that the same approach can be used as an inspection device for production panels.

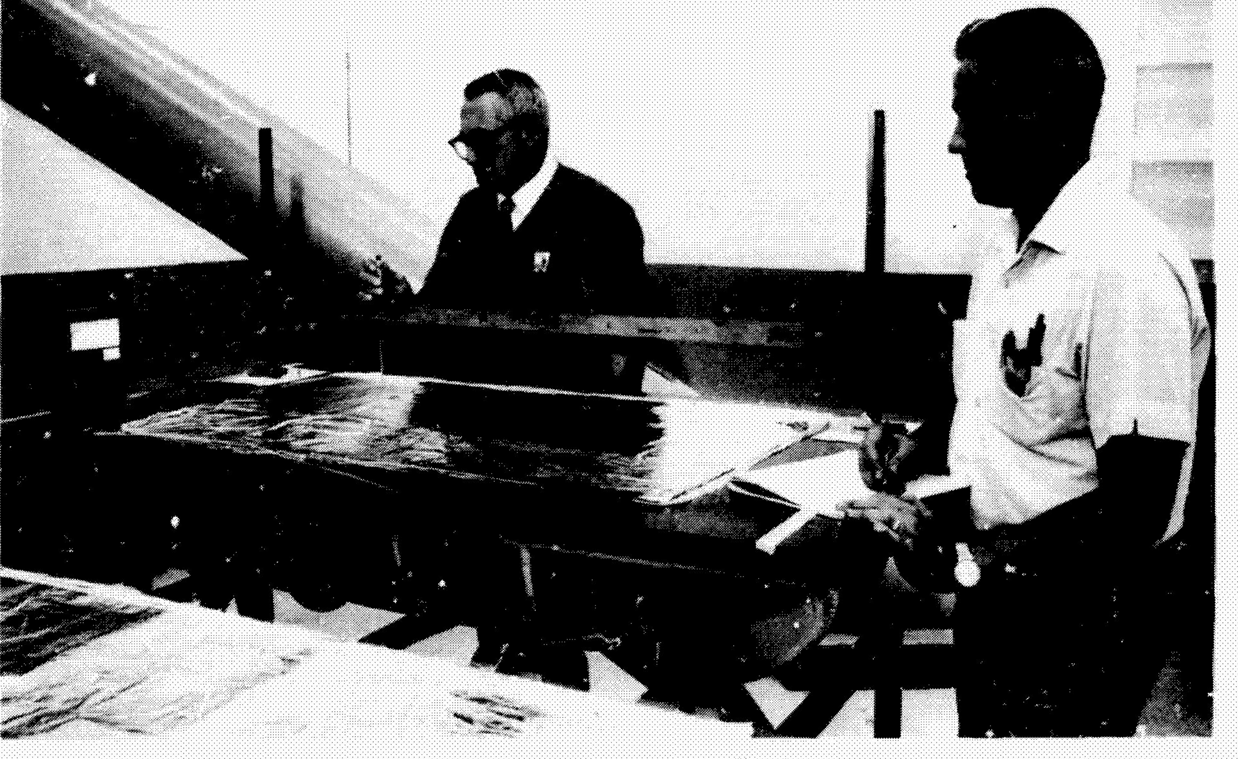


Figure 2-4. Insulation Panel

2.2.4 Settling Measurements

During the course of taking the above measurements, a settling phenomenon was observed; panel thickness had decreased overnight. This observation prompted a change in the study plan to include the acquisition of extended settling data for all systems. Settling as a function of time was monitored by periodically measuring panels stored under cover on work benches (Figure 2-5). As the benches were substantially less flat than the surface table, a profile was taken of each bench surface and thickness measurements corrected to the individual profiles. The settling data measurements are also presented in Appendix A.

2.3 STATISTICAL DATA PROCESSING

The statistical analyses accomplished had two objectives:

1. Define the thickness characteristics of all possible insulation stacks (the population) of N sheets after layup on horizontal tooling.
2. Define if the settling data represented a true independent trend.

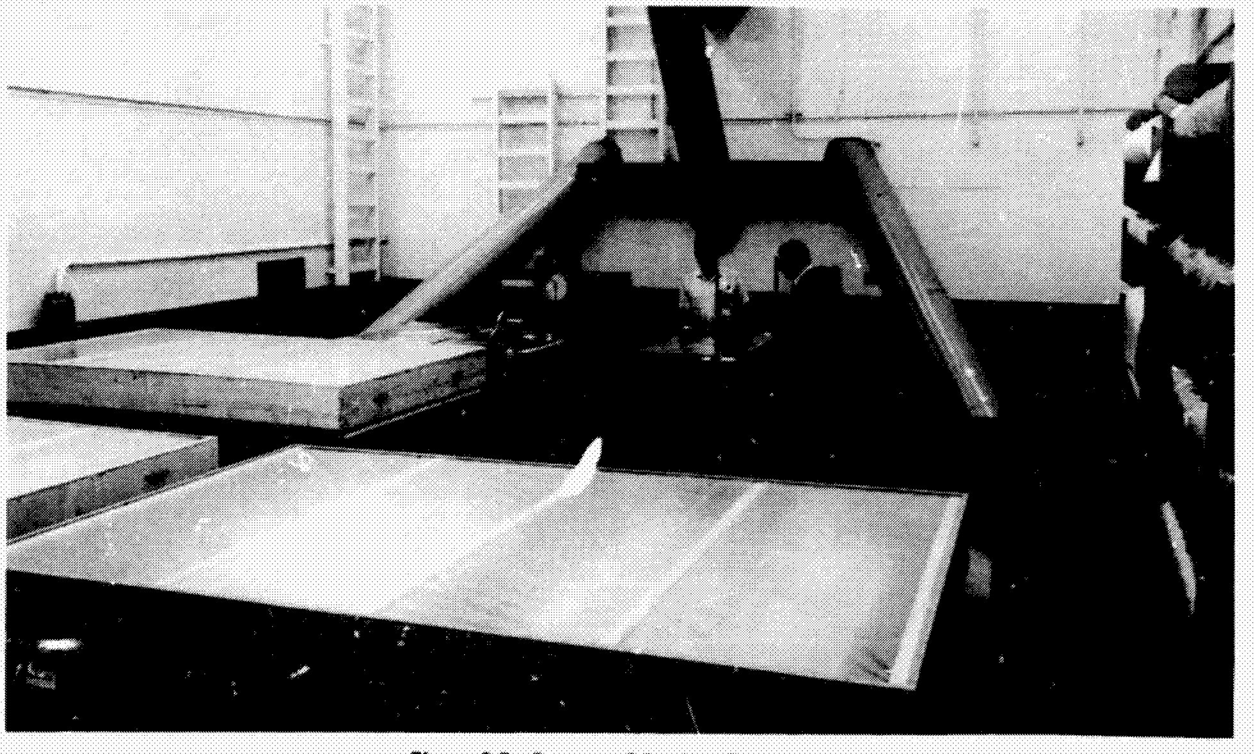


Figure 2-5. Storage of Settling Panels

2.3.1 Stack Thickness

For each of the seven insulation systems investigated there are 270 data points not including the stacked panel data or settling data. These include 135 data points in the initial stacking data and 135 points in the restacked data (see Table A-2, Appendix A, as an example). The 135 data points in either the initial stacking or restacked groups can be further divided into subgroups of 45 data points each for three different numbers of sheets.

The 45 pieces of data were arranged in five columns (one for each sample) of nine thickness measurements per sample. This results in 8 degrees of freedom per column or 40 total. The data were treated as though they were representative of a single distribution, which for a 40 degree of freedom sample would be of size 41.

Variations both within the samples and from sample to sample were included in the evaluation. The variance and mean thickness (average of the nine data points in each column) of each sample were computed. The mean of the variances σ_B^2 and the variance of the means σ_A^2 for the five columns were computed next. The total variance for the 45 data points was computed thusly:

$$\sigma^2 = 5\,\sigma_A^2 + \sigma_B^2$$

Computing the grand average thickness (average of the 45 data points), T_A, there then exists a thickness, T_M, for which it can be stated with confidence C that P percent of the population will have a thickness equal to or greater than T_M. Expressed mathematically,

$$T_M = T_A - K\sigma$$

where K is obtained directly from statistical tables (Reference 3). Table 2-3, obtained from these tables, lists the values of K corresponding to various values of C and P.

The above procedure was applied to the data of Tables A-1 through A-7 of Appendix A to compute T_M. A 90% level of confidence, a value generally accepted by statisticians for this type of application, was used. Results are listed below in Subsection 2.4.

Table 2-3
STATISTICAL RELATIONSHIPS

C	P	K
95%	95	2.0
90%	90	1.59
90%	85	1.31
90%	80	1.10
90%	75	0.93

2.3.2 Settling Trend

The thickness measurements taken during panel storage could represent either a true settling trend (layer density increase) or a thickness change due to random influences. This was resolved by applying a simple standard Chi-Square test to the settling data (Appendix A).

It was found to a very high degree of confidence that settling was acutally occurring for all seven systems. The confidence level indicated by the test was over 90% in all cases.

2.4 RESULTING PARAMETRIC DESIGN DATA

2.4.1 Minimum Layer Density on Layup Tooling

The above statistical data processing method yields the percentage of stacks which can be expected to be thicker than a specific minimum value; in other words, the probability of achieving a manufactured panel of a specified design layer density. This layer density is the practical minimum which can be achieved on initial layup.

Tables 2-4 through 2-10 present this minimum practical design layer density for the seven insulation systems studied. For example, Table 2-4 shows that for a 20-sheet Superfloc panel the minimum practical layer density

Table 2-4

SUPERFLOC-MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets	Acceptance / Rejection Rates					
		95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	10	33.2	30.2	28.5	27.3	26.5	23.2
	15	34.3	31.4	29.6	28.4	27.5	24.1
	20	33.4	31.0	29.5	28.5	27.8	24.8
With Settling	10	36.5	33.2	31.4	30.0	29.2	25.5
	15	37.7	34.5	32.6	31.2	30.3	26.5
	20	36.7	34.1	32.5	31.4	30.6	27.3

Table 2-5

DAM/FOAM MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates					
		95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	17	22.2	21.8	21.6	21.4	21.2	20.6
	20	21.7	21.4	21.3	21.1	21.0	20.6
	23	22.3	21.9	21.7	21.5	21.3	20.7
With Settling	17	22.6	22.2	22.0	21.8	21.6	21.0
	20	22.1	21.8	21.7	21.5	21.4	21.0
	23	22.7	22.3	22.1	21.9	21.7	21.1

Table 2-6

DAM/NYLON NET MINIMUM PRACTICAL DESIGN
LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates					
		95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	20	225	146	118	103	89.5	66.8
	30	102	92.3	86.6	82.8	80.0	69.6
	40	94.5	88.5	84.7	82.1	80.0	72.6
With Settling	20	236	153	124	108	94.0	70.1
	30	107	96.9	90.9	86.9	84.0	73.1
	40	99.2	92.9	88.9	86.2	84.0	76.2

Table 2-7

DAM/DEXIGLAS MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates 95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	20	152	105	86.4	76.4	69.8	51.0
	26	77.4	67.5	62.1	58.6	56.1	47.2
	32	68.6	62.5	58.9	56.4	54.6	47.9
With Settling	20	198	137	112	99.3	90.7	66.3
	26	101	87.8	80.7	76.2	72.9	61.4
	32	89.2	81.3	76.6	73.3	71.0	62.3

Table 2-8

DAM/TISSUGLAS MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates					
		95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	20	106	87.2	77.8	72.0	67.8	61.7
	30	116	98.1	89.0	83.2	79.0	65.0
	40	97.6	85.7	79.2	74.9	71.7	60.8
With Settling	20	127	105	93.4	86.4	81.4	74.0
	30	139	118	107	100	94.8	78
	40	117	103	95.0	90.0	86.0	73.0

Table 2-9

SAME MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates 95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	15	469	184	130	106	92.9	60
	25	141	114	101	93.2	87.6	69.6
	35	259	172	140	123	112	80.7
With Settling	15	516	202	143	117	102	66
	25	155	125	111	103	96.4	76.6
	35	285	189	154	135	123	88.8

Table 2-10

DAME/TISSUGLAS MINIMUM PRACTICAL DESIGN LAYER DENSITY (90% CONFIDENCE)

	Number of Sheets (mylar)	Acceptance / Rejection Rates					
		95%/5%	90%/10%	85%/15%	80%/20%	75%/25%	50%/50%
Without Settling	15	227	120	90.3	76.3	66.0	47.4
	25	196	117	91.9	79.1	71.0	49.5
	35	122	97.3	85.6	78.6	74.0	58.1
With Settling	15	243	128	96.6	81.6	70.6	50.7
	25	210	125	98.3	84.6	76.0	53.0
	35	131	104	91.6	84.1	79.2	62.2

(without modification for settling) is 29.5 sheets per inch if a panel acceptance rate of 85% is to be attained.

2.4.2 Design Layer Density Modification for Settling

The minimum practical design layer density must be increased to account for expected settling. The increase in layer density results in higher thermal conductivity for the insulation. The end result is thus an increase in the amount of insulation required for a particular task. Because the amount of settling data available was, by necessity, limited, only an estimate of the effect can be made. The available data are summarized in Table 2-11 and detailed in Appendix A.

The effect of settling was estimated for each of the seven systems and a factor applied to each set of statistical results. The factor for each system is given in Table 2-12. The effect is shown as an increase in minimum practical layer density shown Tables 2-4 through 2-10 under the grouping denoted "with settling." The layer densities shown, with settling, were used to calculate the study baseline MNV insulation requirements.

Table 2-11
INSULATION SETTLING DATA SUMMARY (page 1 of 2)

Blanket*	Layer Density (sheets per inch) Settling Time (hours) 0	100	200	300	400	500	600	700	800
23 Sheets DAM/Foam	21.0	21.2	21.2	21.2	21.4	21.5	21.7		
92 Sheets DAM/Foam	22.4	22.5							
20 Sheets Superfloc	29.1	31.7	32.0	31.6					
80 Sheets Superfloc	39.1	39.9	40.1 at 144 hrs						
32 Sheets DAM/Dexiglas	39.9	44.3	44.6	45.4	46.0	45.5	48.2	52.2	49.0
128 Sheets DAM/Dexiglas	87.4	88.2	88.9 at 167 hrs						
40 Sheets DAM/Tissuglas	78.6	88.9	88.2	89.0	89.1	89.0	93.5	95.8	94.4
140 Sheets DAM/Tissuglas	113	116	118 at 169 hrs						
35 Sheets DAME/Tissuglas	66.4	67.7	68.2	68.5	69.3	70.5	70.3		
140 Sheets DAME/Tissuglas	88.6	90.4	92.2 at 187 hrs						

Table 2-11 (page 2 of 2)

Blanket*	Layer Density (sheets per inch) Settling Time (hours)								
	0	100	200	300	400	500	600	700	800
40 Sheets DAM/Nylon Net	80.5	81.5	82.7	85.0	84.6	84.1			
160 Sheets DAM/Nylon Net	88.3	92.0							
35 Sheets SAME	99.0	103.3	100.3	106.3	102.9	103.6	109.7	108.5	106.8
140 Sheets SAME	134	138	140 at 170 hrs						

*Number given is the number of reflective separators in blanket. Spacers, for applicable systems, are interspersed.

Table 2-12

SETTLING FACTORS

Insulation System	Settling Factor
Superfloc	10%
DAM/Tissuglas	20%
DAME/Tissuglas	7%
DAM/Nylon net	5%
DAM/Dexiglas	30%
SAME	10%
Foam	2%

Section 3
THERMAL RANKING PROCEDURE AND RESULTS

This section delineates the pertinent parameters required to evaluate the insulation requirements of a typical MNV, the analytical procedure used to make that evaluation, and the results of the evaluation including a thermal ranking of the seven candidate insulation systems. Included is a discussion of the assumed baseline mission and vehicle, the thermal conductivity relationships used for each insulation system, and a discussion of the analytical thermal ranking results.

3.1 BASELINE VEHICLE AND MISSION CHARACTERISTICS

To determine which of several HPI systems is best suited for a particular task it is necessary to establish both the structural configuration to be insulated and the thermal environment that will be experienced. Thus a baseline MNV vehicle configuration and typical mission have been selected which are characteristic of those presently being considered. Tables 3-1 and 3-2 delineate the characteristics pertinent to this study for the vehicle and the mission, respectively.

The vent pressure of 35 psia was selected from MDAC-WD studies which showed this to be a practical upper limit because of the structural requirements during boost governing the tank sizing. The higher vent pressure results in no additional structural weight penalty.

Recent MDAC-WD nuclear stage studies indicate that a total mission heat short of about 1.5×10^6 Btu is reasonable. However, due to the volatility of this parameter, results are presented as a function of total mission heat short as this factor has a strong influence upon insulation requirements.

The thermal capacity of the baseline vehicle - the amount of heat which must be added to the vehicle to increase its pressure from 18 psia to 35 psia - is about 2.9×10^6 Btu for an initial ullage of from 5 to 10%.

Table 3-1

VEHICLE CHARACTERISTICS

Diameter:	396 in.
Cylindrical Section Length:	650 in.
Domes:	$\sqrt{2}$ elliptical
Capacity:	250,000 lb LH_2
Total Volume:	60,000 ft^3
Ullage Volume:	5 to 10%
Surface Area:	8,400 ft^2
Pressure Limits:	
18 psia Initial	
35 psia Vent	
Total Mission Heat Short:	
1.5×10^6 Btu	

Table 3-2

MISSION CHARACTERISTICS

60 Days in Earth Orbit (T_h = 400°R)
210 Days in Transit (T_h = 220°R)
30 Days in Mars Orbit (T_h = 350°R)

3.2 MULTILAYER INSULATION CONDUCTIVITY EQUATIONS

3.2.1 Modification of Existing Equations

Reference 1 presented conductivity equations for various insulation systems. All of these were applicable to mylar of 0.25-mil thickness, except one which is applicable to 0.15-mil material.

This one equation, when compared to its counterpart for 0.25-mil material, shows a difference only in the coefficient of the conduction term. Based on the assumption that other systems would behave in a similar fashion, the coefficients of the conduction terms for these other systems were modified proportionately to yield equations for 0.15-mil material. The resulting equations are:

NRC-2:

$$K_e = 5.10 \times 10^{-12} \bar{N}^2 T_m + \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

Superfloc:

$$K_e = 2.79 \times 10^{-11} (\bar{N})^2 T_m + \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

DAM/Nylon Net:

$$K_e = 5.19 \times 10^{-11} (\bar{N})^{1.4} T_m + \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

DAM/Dexiglas:

$$K_e = 3.96 \times 10^{-12} (\overline{N})^2 T_m + \frac{2.7\sigma(T_h^{\ 2} + T_c^{\ 2})(T_h + T_c)\ t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

DAM/Foam:

$$K_e = 3.03 \times 10^{-15} (\overline{N})^{5.7} (T_m) + \frac{\sigma(T_h^{\ 2} + T_c^{\ 2})(T_h + T_c)\ t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

DAM/Tissuglas:

$$K_e = 1.58 \times 10^{-12} (\overline{N})^2 T_m + \frac{1.7\,\sigma(T_h^{\ 2} + T_c^{\ 2})(T_h + T_c)\ t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

CDAM/Tissuglas:

$$K_e = 4.6 \times 10^{-12} (\overline{N})^2 T_m + \frac{1.7\,\sigma(T_h^{\ 2} + T_c^{\ 2})(T_h + T_c)\ t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

It was further assumed that embossed double aluminized mylar (DAME) has identical thermal performance with crinkled double aluminized mylar (CDAM).

3.2.2 Generation of New Equations from Existing Data

An alternative approach to determining the effective conductivity for the various insulation systems is to use the actual data points presented in

Reference 1 and curve fit by the method of least squares to an equation of the form:

$$K_e = A \bar{N}^X T_m + B \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

where:

$\bar{N}$ = Layer density in sheets/inch

T_m = $(T_h + T_c)/2$

σ = 0.173 Btu/hr-ft^2-$^\circ R^4$

T_h = Hot boundary temperature, $^\circ$R

T_c = Cold boundary temperature, $^\circ$R

t = $N/12\bar{N}$

N = Number of sheets

ϵ = Emissivity

A, B, and X are constants determined by curve fitting to the data.

This approach was also accomplished, the method of solution being to assume an X and calculate A, B, and the standard deviation of the calculated and input values. X was then varied to obtain the minimum standard deviation. The resulting equations, with X computed to the nearest 0.1, are:

NRC-2:

$$K_e = 1.87 \times 10^{-13}\, \bar{N}^{2.7}\, T_m + 1.64 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

$\epsilon_1 = 0.03, \quad \epsilon_2 = 0.4$

Superfloc:

$$K_e = 3.64 \times 10^{-8} \bar{N}^{0.3} T_m - 0.378 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03$, $\epsilon_2 = 0.03$

DAM/Nylon Net:

$$K_e = 3.02 \times 10^{-15} \bar{N}^{3.4} T_m + 2.21 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03$, $\epsilon_2 = 0.03$

DAM/Dexiglas:

$$K_e = 2.89 \times 10^{-18} \bar{N}^{4.9} T_m + 3.88 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03$, $\epsilon_2 = 0.03$

DAM/Foam:

$$K_e = 3.96 \times 10^{-17} \bar{N}^{7.1} T_m + 1.43 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

.:AM/Tissuglas:

$$K_e = 6.29 \times 10^{-23} \bar{N}^{6.8} T_m + 2.84 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03, \quad \epsilon_2 = 0.03$

CDAM (0.25) / Tissuglas:

$$K_e = 2.20 \times 10^{-11} \bar{N}^{1.7} T_m + 4.63 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03, \quad \epsilon_2 = 0.03$

CDAM (0.15) / Tissuglas:

$$K_e = 3.99 \times 10^{-12} \bar{N}^{2} T_m + 2.10 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c) t}{(N-1)(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1)}$$

$\epsilon_1 = 0.03, \quad \epsilon_2 = 0.03$

3.2.3 Comparison of Approaches

3.2.3.1 Comparison of Coefficients and Exponents

The values of ϵ_1 and ϵ_2 used in determining the coefficient of the radiation term are given directly beneath each equation in the previous section. These values may or may not agree with those of Reference 1; however, it is only necessary to adjust the coefficient of the radiation term proportionately to account for this difference. For example, for CDAM (0.25)/Tissuglas the equation becomes:

$$K_e = 2.20 \times 10^{-11} \bar{N}^{1.7} T_m + 1.69 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

for

$$\epsilon_1 = \epsilon_2 = 0.08$$

Also in the region of interest for this material, $\bar{N} = 80$, the product of the coefficient of the conduction term and the layer density raised to its denoted power is within 10% of the same product for the corresponding equation of Reference 1. Thus the equation is not significantly different from that of Reference 1.

3.2.3.2 Choice of Coefficients and Exponents

It is of interest to note that the coefficient of the radiation term in the equation for Superfloc is negative. If X = 2.0 is assumed, the equation becomes:

$$K_e = 3.51 \times 10^{-11} \bar{N}^{2} T_m + 0.96 \frac{\sigma(T_h^2 + T_c^2)(T_h + T_c)\, t}{(N-1)\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)}$$

for

$$\epsilon_1 = \epsilon_2 = 0.03$$

The input values and calculated values for Superfloc with X = 2.0 and 0.3 are depicted in Table 3-3.

Table 3-3

COMPARISON OF SUPERFLOC CONDUCTIVITY FOR TWO DIFFERENT VALUES OF X

$\bar{N}$	Input e	Calculated X = 0.3 K_e	Calculated X = 2.0 K_e
27	2.5×10^{-5}	2.60×10^{-5}	2.71×10^{-5}
28	2.8×10^{-5}	2.67×10^{-5}	2.71×10^{-5}
30	2.8×10^{-5}	2.78×10^{-5}	2.73×10^{-5}
36	2.9×10^{-5}	3.08×10^{-5}	2.92×10^{-5}
41	3.5×10^{-5}	3.29×10^{-5}	3.22×10^{-5}
46	3.4×10^{-5}	3.48×10^{-5}	3.61×10^{-5}

Table 3-3 illustrates that although X, as well as A and B, varies widely, the effect on K_e is small. This is further substantiated by the above discussion on CDAM (0.25) and Tissuglas.

3.2.3.3 Comparison of Effect

The equation for CDAM (0.15) / Tissuglas using A = 3.99×10^{-2}, B = 2.10 and X = 2.0, assumed to be applicable to the DAME (0.15 Mil) / Tissuglas system, was carried through on MNV insulation requirements optimization. The resultant difference when the identical procedures are carried out using the Reference 1 equation is less than 5%.

3.2.4 Conclusions

It was concluded that whether Reference 1 equations or computed equation coefficients based on Reference 1 data are used, the influence on thermal ranking does not appear to be significant. However, both methods extrapolate the equations to temperature boundaries far from their experimentally fitted data points and the accuracy incorporated therein remains a matter of conjecture. And, of course, results are dependent on the accuracy of the experimental data points themselves.

Since it is necessary to extrapolate the conductivity equations from 0.25-mil material to 0.15-mil material and since there does not appear to be a great variation in the final solution with the choice of equation coefficients, the Reference 1 equations modified for 0.15-mil material were used. The primary reason for the choice was that these equations lend themselves to an easier extrapolation to the 0.15-mil thickness material. Also for consistency, the emissivity of aluminized mylar was assumed to be 0.03 and for nonaluminized mylar 0.4 in all cases.

3.3 PARAMETRIC INSULATION OPTIMIZATION

For any given insulation system, vehicle, and mission there exists an optimum amount of insulation, which, if less than an optimum amount is used, the weight so saved will be exceeded by the weight of additional propellant lost; if more than the optimum amount of insulation is used, the additional weight will exceed the weight of propellant saved. The analytical method by which the optimum amount of insulation is determined follows.

Two types of systems are considered. The first system assumes there is no boiloff or propellant lost. The second system assumes that there will be boiloff or propellant loss. Solutions to both systems are determined and the optimum is that solution which is the lightest in weight.

3.3.1 Optimization Without Boiloff

For the solution to a no boiloff system, the following three parameters must be evaluated:

1. The total amount of heat which will pass through the thermal insulation over the duration of the mission.
2. The total amount of heat which passes into the propellant during the duration of the mission from plumbing, instrumentation, and other thermal shorts. Nuclear heating, if applicable, must also be considered.
3. The thermal capacity of the propellant.

The latter quantity can be calculated from volume and thermophysical properties of the tank and its contents. For a cryogenic propellant tank it is simply the amount of heat which must be added to increase the pressure from its value at the beginning of the mission to the vent pressure.

The thermal flux through the heat shorts depends upon mission duration times, cross-sectional areas, path lengths, temperature boundaries, thermal properties, etc. Since these parameters are relatively undefined and subject to change, the heat short was assumed to be 1.5×10^6 Btu for the baseline vehicle and mission. This is representative of vehicles currently under study.

The amount of heat passing through the insulation is solvable if the area, temperature boundaries, and thermal properties of the insulation are known:

$$Q_{\text{thru ins.}} = \frac{(\text{Area})\ (12)\ (\bar{N})}{N} \left(\Sigma (K_i \Delta T_i \Delta \tau_i) \right)$$

where

K_i is the thermal conductivity during the ith portion of the mission,

ΔT_i is the temperature difference during the ith portion of the mission, and

$\Delta \tau_i$ is the duration of the ith portion of the mission.

Table 3-2 lists the three baseline mission environmental portions used for the insulation analyses.

The optimum quantity of insulation is that amount which allows only enough heat to pass through such that this amount of heat plus the heat through the shorts is identically equal to the thermal capacity. Of course, if the heat short flux exceeds the thermal capacity, then a no-boiloff solution is impossible.

3.3.2 Optimization with Boiloff

When boiloff occurs, the solution for an optimum amount of insulation is slightly more complex. If the mass of the propellant boiled off is M_B and the mass of the insulation is M_I, then the thermal weight penalty (TWP) is:

$$TWP = M_B + M_I$$

The solution to the equation

$$\frac{d\,(TWP)}{dM_I} = O$$

produces the optimum amount of insulation for a system with boiloff. This solution will be independent of both the heat short flux and the thermal capacity of the storage area and hence must be compared with a no-boiloff solution to insure validity. For example:

$$M_B = \frac{\text{Q Thru Ins.} + \text{Q Shorts} - \text{Q Capacity}}{\text{Heat of Vaporization}}$$

but any solution to

$$\frac{d\,(TWP)}{dM_I} = O$$

is valid only if M_B is a positive value.

3.3.3 Parametric Results

The optimum amount of insulation is the smaller of the two solutions:

1. $M_B = O$
2. $\frac{d\,(TWP)}{dM_I} = O$

Tables 3-4 through 3-10 give the parametric optimization data (optimum number of layers and MNV thermal weight penalty) generated from the vehicle and mission characteristics denoted in Subsection 3.1, and the conductivity equations of Subsection 3.2, for the seven candidate insulation systems. Data are presented as a function of total mission heat short as this factor has a strong influence upon insulation requirements. The vent pressure also has a strong influence upon insulation requirements. Decreasing the vent pressure from 35 to 30 psia decreases the thermal capacity of the propellant by almost 900, 000 Btu. The effect is identical to increasing the total mission heat short 900, 000 Btu. It is roughly estimated that for such a case the insulation requirements and thermal weight penalties would be two to three times those shown.

Table 3-4
SUPERFLOC PARAMETRIC INSULATION REQUIREMENTS
OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (sheets/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
24	12.8 177	14.4 199	16.4 226	18.8 259	22.2 304	27.1 375
27	15.2 210	17.0 234	19.3 267	22.3 308	26.3 364	32.3 444
30	18.1 250	20.2 279	22.9 315	26.3 365	31.2 430	38.1 528
33	21.9 301	24.3 336	27.5 380	31.8 439	37.5 518	46.0 633
36	26.5 366	29.5 406	33.4 461	38.5 532	45.5 628	55.6 769

*As a function of layer density and total mission heat short.

Table 3-5

DAM/TISSUGLAS PARAMETRIC INSULATION REQUIREMENTS

OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (pairs/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
90	29 500	32 550	36 630	42 740	50 880	61 1080
105	39 680	43 760	49 860	57 1000	67 1180	81 1450
120	52 920	58 1030	66 1170	76 1340	89 1590	109 1950
135	69 1220	77 1360	87 1550	100 1790	119 2120	145 2580
150	88 1560	98 1750	111 1980	128 2280	152 2700	186 3320

*As a function of layer density and total mission heat short.

3.3.4 Dual Optimization

In the optimization procedures delineated in the preceding sections it has been assumed that the MNV insulation will be uniform over all parts of the vehicle, i.e. there will be the same amount of insulation, and at the same layer density, on the sidewall areas as on the dome areas. In reality this will not be the case because dome area insulation will be under compression due to its own weight. Since it is under compression, its layer density will be higher and thus its thermal conductivity will be higher. Hence more insulation will be required in these areas. The optimization data of Tables 3-4 through 3-10 are also applicable to determining this amount of insulation. It is recommended that future detailed analyses of MNV insulation requirements include determining the optimum amount of insulation on both sidewall and dome or other areas.

Table 3-6

DAME/TISSUGLAS PARAMETRIC INSULATION REQUIREMENTS

OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (pairs/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
60	26 470	29 520	33 590	38 680	45 820	56 1000
70	35 630	39 690	45 790	51 910	61 1080	74 1320
80	46 840	51 920	58 1040	67 1200	80 1420	97 1740
90	59 1050	66 1170	74 1330	85 1530	101 1810	124 2210
100	79 1420	89 1580	100 1790	115 2070	136 2240	167 2990

*As a function of layer density and total mission heat short.

For both sidewall and dome areas there exists an optimum amount of insulation, which, if less than optimum amount is used, the weight so saved will be exceeded by the weight of additional propellant lost, or, if more than the optimum amount of insulation is used, the additional weight will exceed the weight of propellant saved. Having found the optimum amount of insulation required on both the dome and sidewall areas, as indicated above, it might be concluded that the insulation system has been completely optimized. However, there exists an additional optimization procedure which can be performed, dual optimization.

If a small piece of insulation is removed from the dome area (high layer density area), there will be a net increase in heat flow to the tank, ΔQ_D. Now if that piece of insulation is placed on the sidewall area (low layer

Table 3-7
DAM/DEXIGLAS PARAMETRIC INSULATION REQUIREMENTS
OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (pairs/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
60	31.5 1130	35 1270	39.5 1430	46 1660	54 1970	66 2410
65	35 1250	39 1400	44.5 1590	51 1850	60 2190	73.5 2480
70	39 1400	43.5 1550	49.5 1790	57 2170	67 2240	82 3000
75	43.5 1570	48.5 1750	55 2000	63.5 2310	75 2730	91.5 3350
80	48.5 1750	54 1950	61 2230	70.5 2570	83.5 3050	102 3730
85	54.5 1960	60.5 2200	68.5 2500	78 3890	93.5 3430	114.5 4190

*As a function of layer density and total mission heat short.

density area), there will be a decrease in the heat flow to the tank, ΔQ_S. Since the layer density is lower on the sidewall area, the piece of insulation is more effective in this location and $\Delta Q_S > \Delta Q_D$. Thus only a percentage of the piece of insulation removed from the dome need be placed on the sidewall to maintain the same heat flow to the tank. As additional pieces of insulation are removed from the dome area, the ΔQ_D of each will increase. Similarly for each piece ΔQ_S will increase requiring a higher percentage of each piece to be added to the sidewall area. Eventually there will come a point when $\Delta Q_S = \Delta Q_D$ when all of the piece removed from the dome area is placed on the sidewall area. At this point the system is dually optimized because any additional transferring of insulation will not result in any additional weight savings.

Table 3-8

DAM/NYLON NET PARAMETRIC INSULATION REQUIREMENTS

OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (pairs/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
75	31 1000	34.5 1120	39 1270	45.5 1470	53.5 1750	65.5 2150
80	35 1130	39 1270	44 1430	51 1660	60.5 1970	73.5 2420
85	39.5 1280	44 1430	50 1630	57.5 1880	68 2230	83 2730
90	44 1430	49 1600	56.5 1820	64.5 2100	76 2500	93 3050
95	49 1600	55 1800	62.5 2040	72 2350	85 2780	104 3410
100	54.5 1780	61 2000	69 2270	80 2610	94.5 3100	115.5 3790

*As a function of layer density and total mission heat short.

The applicable dual optimization equations are presented here for future reference. Letting T be temperature, τ time, and subscripts D and S refer to dome and sidewall areas then:

$$Q_D = 12A_D\ (\overline{N}_D/\overline{N}_D)\ (K_D \Delta T \Delta \tau)$$

$$Q_S = 12A_S\ (\overline{N}_S/\overline{N}_S)\ (K_S \Delta T \Delta \tau)$$

Table 3-9

SAME PARAMETRIC INSULATION REQUIREMENTS

OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (sheets/inch)	Total Mission Heat Short (Millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
90	67 660	75 740	85 840	98 970	117 1160	141 1410
105	95 940	106 1040	120 1180	139 1370	164 1620	200 1980
120	142 1400	158 1570	179 1780	208 2050	246 2430	300 2960
135	195 1940	220 2180	249 2460	286 2840	339 3350	415 4100
150	265 2620	296 2920	335 3310	387 3820	456 4500	527** 5510**

*As a function of layer density and total mission heat short.

**With boiloff

For dual optimization:

$$(dQ_D/dN_D)/(dQ_S/dN_S) = A_D/A_S$$

or

$$(K_D\bar{N}_D/\bar{N}_D^{\,2}) = (K_S\bar{N}_S/\bar{N}_S^{\,2})$$

which gives the optimum number of sheets for dome and sidewall areas:

$$N_S = (12/Q_{INS})\,(A_D\,(K_D\bar{N}_D K_S\bar{N}_S)^{1/2} + A_S\bar{N}_S K_S)\;\Delta T\;\Delta\tau$$

Table 3-10

DAM/FOAM PARAMETRIC INSULATION REQUIREMENTS

OPTIMUM NUMBER OF LAYERS
THERMAL WEIGHT PENALTY (LB)*

Layer Density (pairs/inch)	Total Mission Heat Short (millions of Btu) 1.0	1.2	1.4	1.6	1.8	2.0
18	18.8 1110	20.9 1230	23.7 1410	27.4 1620	32.4 1950	39.5 2390
19	23.1 1370	25.9 1540	29.3 1750	33.8 2050	39.9 2430	48.8 2980
20	30.0 1820	33.4 2020	38.0 2300	43.9 2660	51.8 3160	63.3 3840
21	39.4 2390	44.0 2680	50.0 3060	57.6 3520	68.2 4180	81.1** 5000**
22	51.0 3130	57.0 3480	64.5 3950	74.5 4570	88.0 5400	92.2** 6490**
23	65.6 4020	73.2 4490	83.0 5110	95.8 5890	104.7** 6940**	104.7** 8020**

*As a function of layer density and total mission heat short.

**With boiloff

$$N_D = N_S (K_D\bar{N}_D/K_S\bar{N}_S)^{1/2}$$

where Q_{INS} is the permissible heat flux through the insulation.

2

3.4 MNV INSULATION REQUIREMENTS

The insulation parametric optimization data contained in Subsection 3.3 were used with the statistical data of Subsection 2.4 to determine, for each of the seven systems, the insulation requirements for the baseline MNV exposed to the baseline mission. This procedure is detailed in the following paragraphs and a numerical example is given in Appendix B.

3.4.1 Application of Density Study Data

In the measurement study it was found that if a specific number of sheets of a given insulation were laid up, the thickness of the resulting panel would vary due to slight nonhomogeneous materials and/or slight variations in layup procedure and the personnel involved in the layup operation. Statistical efforts applied to the resulting frequency-thickness distribution allowed predicting, with a predetermined confidence level, the probability of a given panel having a specified or greater thickness. Since layer density is inversely proportional to thickness, one can predict the probability of obtaining a specified or lower layer density. It was found that low layer densities could be achieved only by rejecting a high percentage of constructed panels. Similarly, if the upper limit on layer density was high, only a low percentage of panels need be rejected. It was arbitraily decided that a rejection rate higher than 25% would be unacceptable. The insulation requirements and thermal weight penalties for each insulation system were therefore calculated for rejection rates near this value.

3.4.2 Application of Settling Data

It was also necessary to include the effect of insulation settling and degradation due to manufacturing in calculating thermal weight penalties. The manufacturing degradation (installation of buttons, etc.) was found to be very small and was therefore neglected. The natural settling of the insulation is however quite significant. Although settling data are given in Subsection 2.4, it is not of sufficient depth to make accurate predictions. However, layer densities given in the statistical results of Subsection 2.4 were increased a percentage amount based on the existing data. The percentage values for each insulation system are denoted in Table 2-12.

3.4.3 Calculation Procedure

Based on the above considerations (the statistical data of Subsection 2.4, and the optimization results of Subsection 3.3), the MNV insulation requirements were calculated for with each of the seven candidate systems. Table 3-11 illustrates the procedural steps for the calculation.

Table 3-11

PROCEDURE FOR THE DETERMINATION OF MNV INSULATION REQUIREMENTS

1. Select a rejection rate.
2. Select a layer density range of interest (with settling).
3. Determine range of optimum number of sheets, N.
4. Select an N within the range of optimum N.
5. Determine the number of panels, P.
6. Divide: $N/P = N_P$, number of sheets per panel.
7. Determine layer density for N_P, LD_P.
8. Determine optimum N, $N_{opt.}$, for LD_P.
9. Does $N_{opt.}$ equal the N selected in step 4?

NO	YES
Iterate steps 4 through 9.	Solution $N = N_{opt.}$ $LD = LD_P$ TWP

A numerical example is illustrated in Appendix B. The resulting optimum number of layers, layer densities and thermal weight penalties are applicable to a vehicle insulated as if all the insulated areas behaved as sidewall insulated areas. The optimum number of layers and resulting insulation weights will be slightly higher in the dome areas and can be obtained by assuming P = 1 in the outlined procedure. To determine the thermal weight penalties for a MNV with different amounts of insulation on the dome and sidewall areas it is only necessary to sum the insulation weights of the individual areas:

$$TWP = (N_S A_S + N_D A_D) \text{ (insulation weight/sheet-ft}^2\text{)}$$

The effect is an increase in TWP for all systems. Dual optimization (Subsection 3.3.4) would tend to decrease TWP slightly. Considering both effects, the result is only a slight increase in TWP. A sample point was computed for both the Superfloc and DAME/Tissuglas systems with a resultant change in TWP of less than 10%. Thus it was concluded that a thermal ranking of the seven insulation systems based on the assumption that all areas of the MNV behave as sidewall areas is qualitatively valid and this analytically simpler approach was used. For a more detailed design of an insulation system on a MNV the more quantitatively accurate approach is recommended.

3.4.4 MNV Thermal Weight Penalty

Figure 3-1 illustrates the thermal weight penalty for each of the seven investigated systems as a function of fabricated panel rejection rate. It will be noticed that the relationship is represented by a dashed line in certain regions. This represents regions where either the layer density study data are insufficient or where extrapolation of the analytical optimization data was required. Table 3-12 presents more explicit information at the 25% rejection level. Certain minor discrepancies exist between the values for thermal weight penalty given in Table 3-12, Figure 3-1, and the data of Tables 3-4 through 3-10. These discrepancies do not affect the relative rankings of the systems and are a result of the necessity of choosing number of layers evenly divisable by the proposed number of panels as described in the next section.

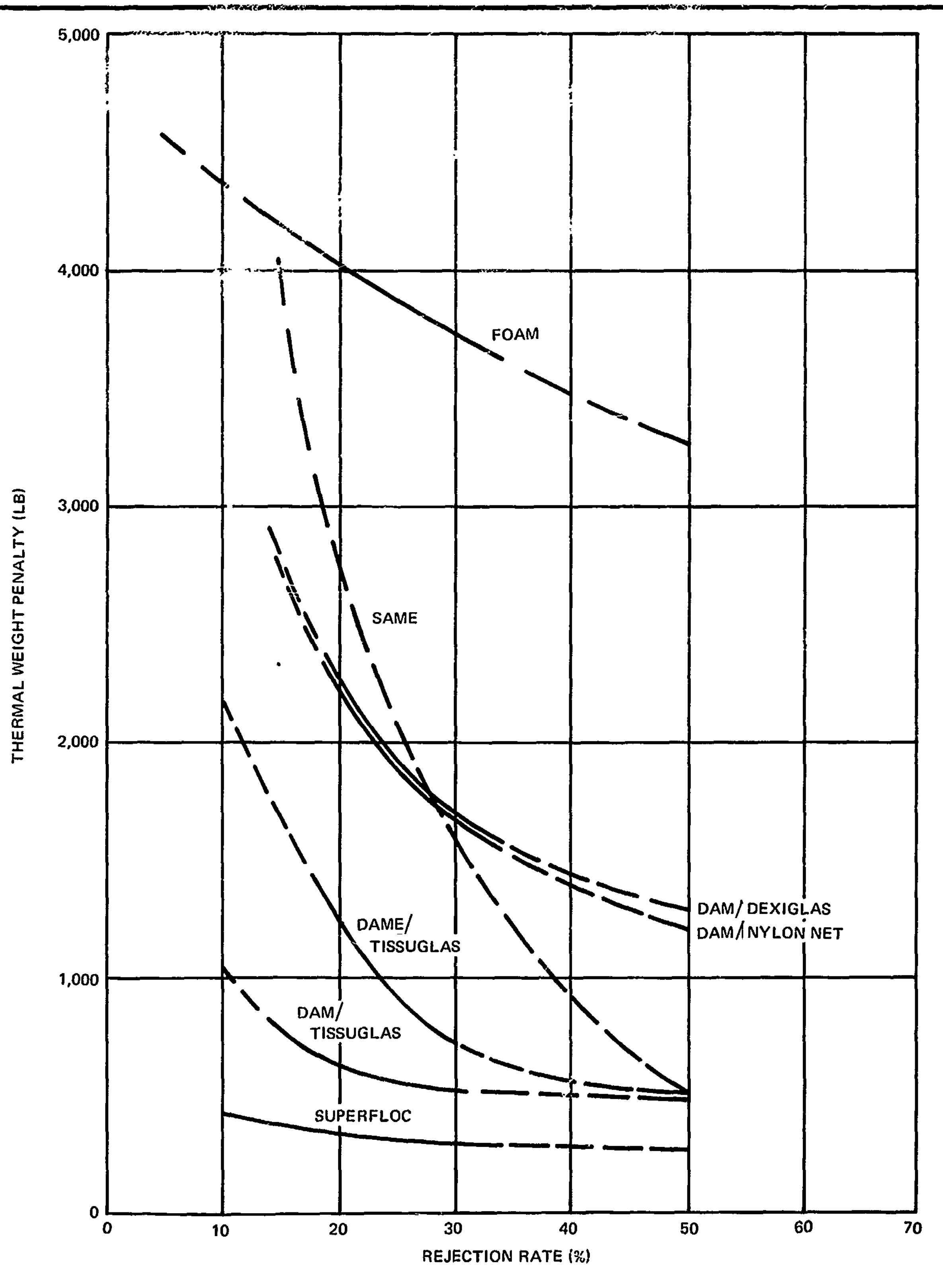


Figure 3-1. Effect of Rejection Rate on Thermal Weight Penalty

Table 3-12
MNV INSULATION REQUIREMENTS
(at 25% Rejection Rate)

Insulation System	Number of Layers	Layer Density	Thermal Weight Penalty (lb)
Superfloc	24	29	330
DAM/Tissuglas	33	82	580
DAME/Tissuglas	54	72	900
DAM/Dexiglas	53	70	1920
DAM/Nylon net	63	91	2000
SAME	216	123	2050
DAM/Foam	68	21.7	3900

3.5 THERMAL PERFORMANCE RANKING

3.5.1 Ranking Criteria

The number of sheets of insulation required to insulate the baseline MNV for the baseline mission at a 25% manufacturing rejection rate was presented in the previous section. Also included was the minimum practical layer density and total insulation weight for each system. Since no boiloff occurs with any of the systems they are thermally identical – each allows the same amount of heat transfer over the duration of the mission. Since all systems will do the job equally well, the only difference and hence the only thermal ranking parameter used is weight.

3.5.2 Thermal Ranking

Table 3-12 lists the seven insulation systems in order of increasing weight. That table is the thermal ranking of the insulation systems.

The insulation weights given in Table 3-12 are insulation weights only and do not include the weight of any attachment fittings, buttons, or the like. Thus the actual weights will be somewhat higher for all systems. It is doubtful that the relative rankings of the systems will change, but this cannot be determined absolutely at this time.

Although NRC-2 was not one of the seven insulation systems investigated, certain preliminary calculations were made to determine its probable relative ranking. Calculations were based on the equation given in Reference 1, the baseline mission and vehicle denoted in Tables 3-1 and 3-2, and at an assumed layer density of 70 sheets per in. The resultant thermal weight penalty was found to be about 900 pounds. Since no layer density study was performed with this material, it is not possible to associate a rejection rate with that value.

The most striking feature of the thermal ranking results is that the amount of insulation required, and hence the system weights, are considerably lower than those previously published or obtained with other studies. There are several reason for this, the most important of which is the assumed vent pressure of the baseline vehicle. The baseline vehicle has a thermal capacity of 2.9×10^6 Btu with an 18-psia initial pressure and a 35-psia vent pressure. Of this total, 1.5×10^6 Btu will be utilized by the heat coming through the plumbing and other shorts. This leaves an absorbing capacity of 1.4×10^6 Btu for heat coming through the insulation. Reducing the vent pressure to 30 psia is approximately equivalent to reducing the thermal capacity by 900,000 Btu, or reducing that amount of heat allowable through the insulation to 500,000 Btu. It is therefore roughly estimated that the insulation requirements with a 30-psia vent pressure on the vehicle would be two to three times the above stated value.

A second factor which can influence system weight strongly in the assumed heat short value. Any increase in the heat short is an equivalent decrease in the allowable amount of heat through the insulation resulting in a corresponding increase in the amount of insulation required.

Another factor which can have a strong influence on the amount of insulation required is the assumed boundary temperatures or mission environment. For example, with 24 sheets of Superfloc at a layer density of 29 sheets per inch the heat flux through the insulation with a liquid hydrogen cold boundary temperature (37°R) is 0.1464, 0.0563, 0.0377, and 0.0130 Btu/hr-ft^2 with hot boundary temperature of 540°R, 400°R, 350°R, and 220°R, respectively. For the assumed mission this amounts to approximately 230,000 Btu during the 30-day Martian orbit, 550,000 Btu during the 210-day transit period, and 680,000 Btu during the 60-day earth orbit. Thus the advantage of keeping the hot boundary temperature as low as possible and the duration of high hot boundary temperatures as short as possible is evident.

The results are also quite dependent on the validity of the thermal conductivity equations. The validity can be checked only by additional testing with amounts of insulation realistically characteristic of those that would be used on an actual MNV and preferably at boundary temperatures characteristic of those expected on a typical MNV mission.

Although the results of this thermal ranking can be influenced by changes in any of the assumed influencing parameters such as vehicle characteristics, mission duration and environment, insulation thermal characteristics, etc., the general approach to ranking is valid.

Section 4
FABRICABILITY RANKING

Realistic ranking of insulation systems must consider fabricability in addition to thermal performance to (1) establish manufacturing feasibility; (2) avoid incurring excessive fabrication costs in return for meager system weight savings; and (3) include a measure of the level of confidence for achieving repeatable thermal performance. The fabricability ranking approach used previously, shop estimates of "ease of fabrication", has serious shortcomings. It results in disagreement among investigators, neglects other important criteria, and yields measures that have questionable utility because they are essentially intangible.

A meaningful ranking must be based on a more thorough quantitative evaluation. This goal was successfully accomplished in this study by basing rankings on data gathered through actual fabrication of typical sections of MNV panels, one for each of the candidate systems. This approach to ranking has several benefits: fabrication difficulties could be noted for each system and their impact on ranking evaluated; and representative manufacturing cost data could be obtained to provide a direct comparison between systems. The value of the intangible "shop preference" factor could also be assessed.

Panel fabrication provided two other important results needed for meaningful ranking of systems: measurement of any density increases due to installing fasteners, required for assessment of heat transfer performance and thermal ranking; and the demonstration of repeatably manufacturing to the desired design density. The following sections describe this panel fabrication work and the resulting fabricability ranking of the candidate systems.

4.1 PANEL FABRICATION

One 4 by 5 foot panel was fabricated from each of the seven candidate insulations. These panels were assembled with rigid stud and button fasteners and dacron net face sheets as recommended in Reference 1. Panel thicknesses corresponded to the minimum practical densities for MNV requirements (Table 4-1). It will be noted that the values for MNV requirements in Table 4-1 differ in some cases from those in Table 3-12. This was due to the necessity of initiating panel fabrication concurrently with final thermal analyses. Panels of the Superfloc DAME/Tissuglas and SAME systems were fabricated prior to establishment of the 25% rejection criterion; the densities of panels built for these systems are for lower rejection rates (higher layer densities). DAM/nylon net and DAM/Tissuglas densities in Table 4-1 are one layer per inch lower than the final MNV densities (Table 3-12). However, this discrepancy in no way influences the study results.

4.1.1 Fabrication Method

The fabrication method developed to produce panels with repeatable layer density was based on the following design approach: (1) design thickness would be maintained by the rigid stud and button fasteners; (2) gross variation in panel thickness due to quilting would not be allowed; and (3) density control would be achieved by reducing the initial panel thickness on the layup tool to the required thickness. This approach yields a panel thermal performance which is as predicted or slightly better.

A minimum practical density can be defined by the method reported in Section 2. With this new information, a conventional fabrication method — a base plate with mating top plate — can now be used for the first time, with confidence, in achieving repeatability. Further, repeatable fabrication can be achieved by any manufacturer.

The fabrication procedure, identical for each panel, used in the study is outlined below: The required number of sheets of insulation were stacked on a 4 by 5 foot base plate with a dacron net face sheet at the bottom of the stack. Each sheet was taped down after adding it to the stack. The panel thickness

Table 4-1

PANEL FABRICATION REQUIREMENTS

Insulation System	MNV Requirements: Layer Density	MNV Requirements: Number of Sheets	Panel Requirements: Number of Panels	Panel Requirements: Number of Sheets	Panel Requirements: Thickness (in.)
Superfloc	33	33	3	11	0.333
DAM/Foam	22	72	4	18	0.810
DAM/Nylon net	90	63	3	21	0.222
DAME/Tissuglas	76	60	3	20	0.253
SAME	128	216	4	54	0.422
DAM/Tissuglas	81	34	2	17	0.198
DAM/Dexiglas	70	54	3	18	0.243

NOTE: 1. Number of sheets refers to the number of reflectors. For the two-component systems, the number of separators per panel is one sheet less than the number cited.

2. The thickness shown was based on the number of separator sheets required.

was then reduced to the design thickness by adding the top plate. Measurements were then made to determine the effect of inserting rigid stud fasteners on 24-, 12- and 6-inch centers. These studs are inserted in an insulation panel by prepunching holes for the studs with hypodermic needles. Panel fabrication was completed after measurements of local compression had been obtained. The top plate was removed and the outer layer of dacron net (initially left out to facilitate measurements) added to the panel. Top plate repositioning for permanent anchoring of stud fasteners on a 12-inch center pattern followed. After stud installation, the panel was trimmed to final dimensions. This operation was followed by a final thickness survey, measuring thickness between fastener points.

4.1.2 Tooling

Major panel fabrication tooling, shown in Figure 4-1, consisted of two rectangular flat plates separated by spacers positioned near each plate corner. These plates had mating clearance holes at fastener attachment points.

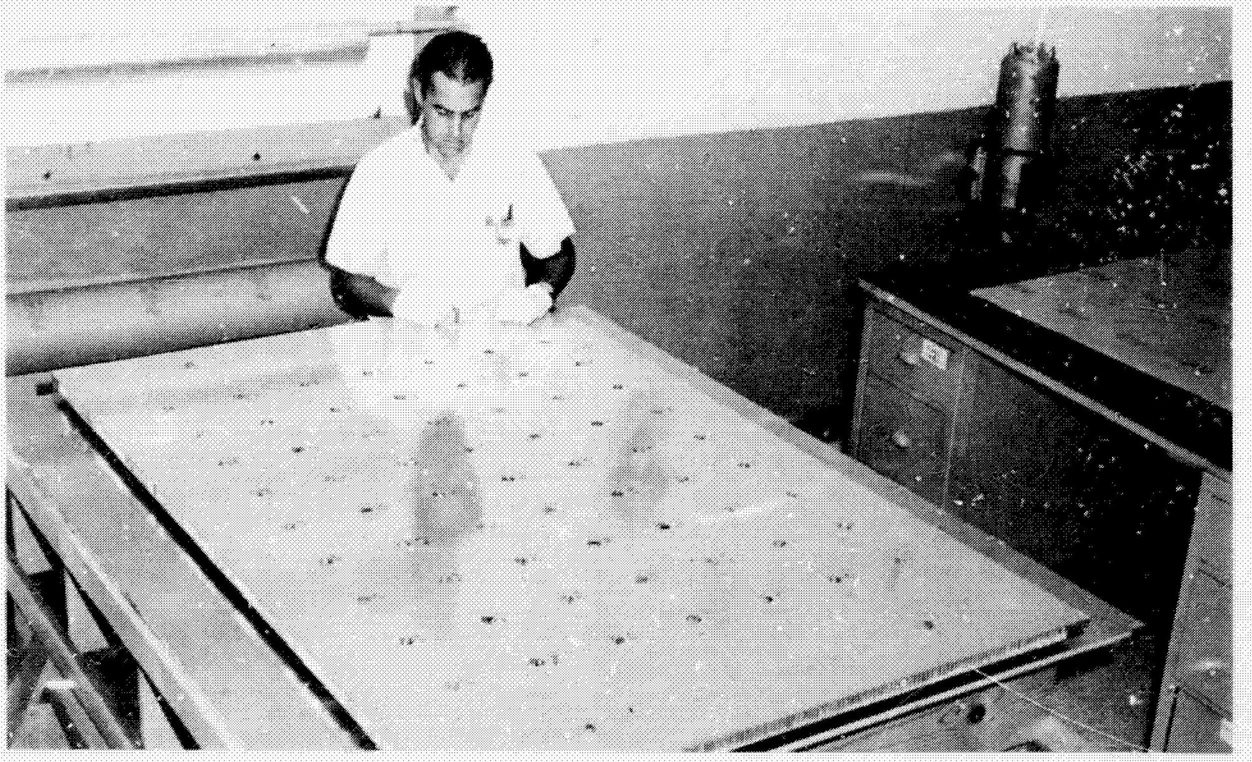


Figure 4-1. Panel Fabrication Tooling

Special care was taken in plate design to ensure that panel thickness measurements would be truly independent of tooling. To achieve this goal, two flat surfaces were required, the top of the base plate and the bottom of the top plate. Honeycomb panels were selected. The bottom layup plate, which is supported at several points, has nominal 0.050-inch-thick, 2014-T6 aluminum skins over an 0.050-inch-thick aluminum honeycomb core. The top plate, supported only at four points on the outer edges, has identical face sheets on a 1-inch core. One flat surface on each plate was achieved by using a vacuum bag pressure method of fabrication on an inspection table as the flat platen. Surface profile measurements in Appendix A show a maximum flatness deviation of ±0.013 inch.

Plate separation spacers that control the final insulation panel thickness were machined from 2-inch-diameter aluminum alloy rod, with the height dimension held within 0.002 inch. Center bolt holes in the spacers indexed the two plates. Since each system had a different design thickness, seven sets of spacers were required. Beam deflection in the top plate, supported by a set of four spacers, was a maximum of 0.005 inch. These measurements are also presented in Appendix A.

A foam-filled cylinder was inserted in the bottom plate clearance holes during the punching operations for stud insertion. This technique ensured that the insulation was not pushed into the hole as the needle punch was inserted through the insulation. The cylinder along with other accessories used in the fabrication study are shown in Figure 4-2. A needle guide for centering the needles in the clearance holes is shown in the figure at the lower left. A typical set of spacers and cutting fixtures to control stud length is shown at the top of the figure.

The punches used were conventional 18-gage hypodermic needles with an 0.032-inch inside diameter. Needles were used as they cut relatively clean holes and provide a guide for the stud. Size 18 was selected since it is expected that a final design study would have an outside diameter on the order of 0.030 inch. The tops of the needles were removed so they would remain erect in the panel during local compression measurements.

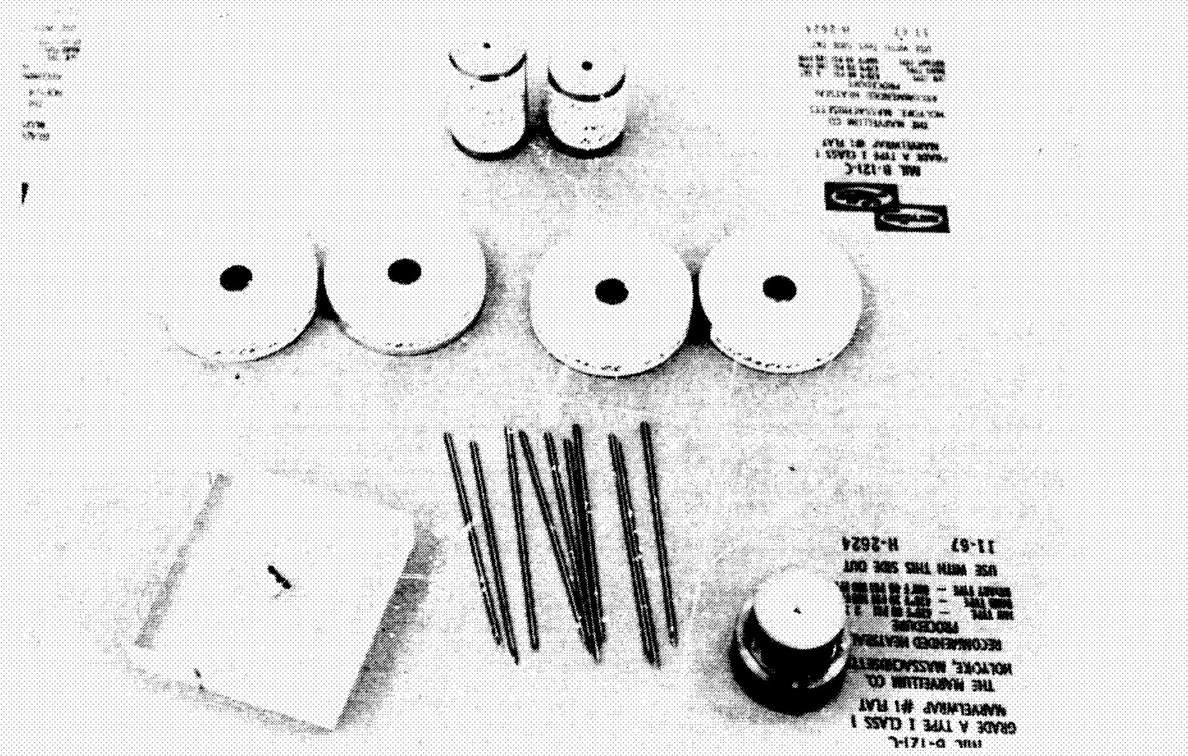
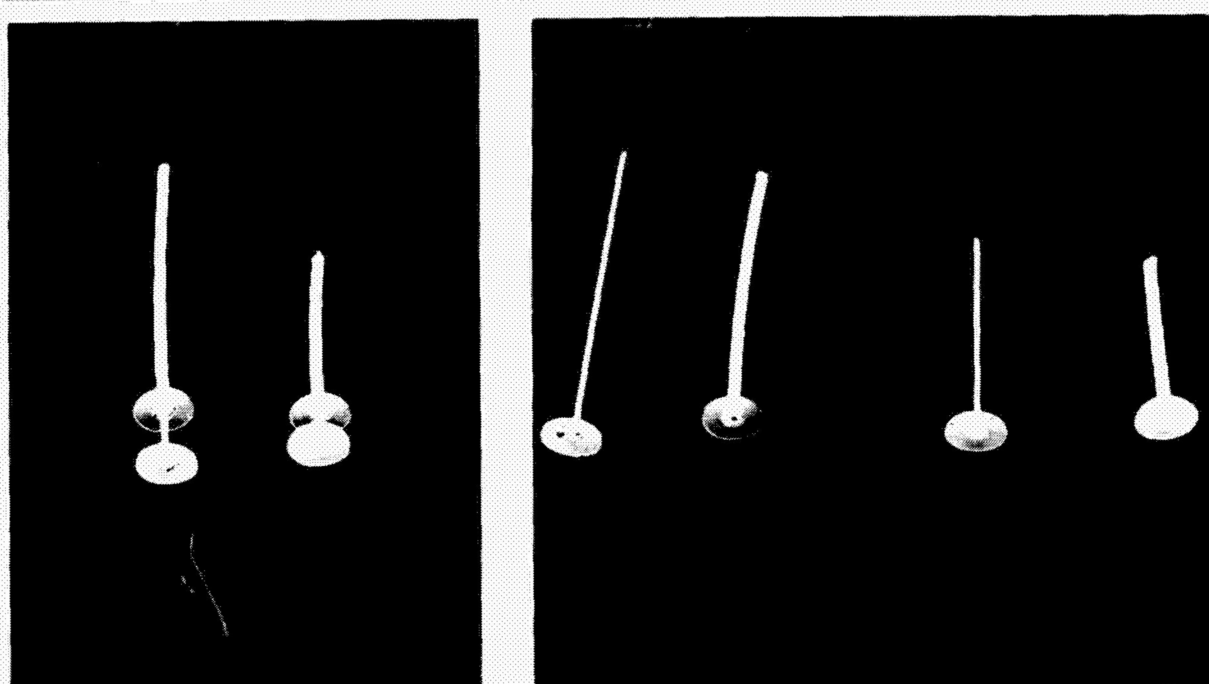


Figure 4-2. Panel Fabrication Accessories

4.1.3 Fasteners

Panel thickness, and thus fastener length, varied with each system. Because it was not considered cost effective to purchase molds for each fastener length required, a simulated stud was developed and used. Since length, the important parameter, was controlled, these fasteners demonstrate the concept as accurately as would the use of a production fastener. These simulated stud and button fasteners are shown in Figure 4-3. Since structural integrity and not heat transfer was the only criterion for these panels, the studs were developed using readily available materials and an inexpensive fabrication technique. An 0.062-inch outside diameter nylon rod, the smallest readily available, governed size. The buttons were punched from nylon sheet stock, nominal 0.035-inch thick and attached to the rods and tubes with a heat-sealing technique.



A B

Figure 4-3. Simulated Rigid Stud Fasteners

The top button was positioned by inserting the tubular component over the rod and heat-sealing in position. Spacing control between the buttons, which determines panel thickness, was achieved by controlling the lengths of the stud and the tubular top button support. Two accommodate all systems, two rod lengths were used, 1.500 and 2.000. The required length of a tubular top button support for a given system is equal to the rod length minus the sum of the design thickness and the top button thickness. As the length of the studs between the buttons was the critical parameter, the cutting fixtures to hold these lengths within ±0.001 inch were machined from steel rod stock; two fixtures for each of the insulation systems. The excess tubular material was cut off with a hot knife after fasteners had been installed in the panel.

4.2 EFFECT OF FASTENER INSERTION ON PANEL DENSITY

It was believed that punching compression effects could be a function of fastener spacing. Final design spacing is not yet known but a 12-inch square pattern has been recommended (Reference 1). For some areas, particularly the domes, where material must be cut to contour to a compound curvature surface, the spacing might be less than 12 inches. Therefore, effects of inserting fasteners on 24-, 12- and 6-inch centers were investigated to evaluate the problem thoroughly.

It was also felt that such compression effects could be minimized by preventing individual sheet movement during punching. This was accomplished during the initial layup; each sheet of material was cut oversize and taped to the base plate. Caution was exercised in this step to assure that there was no tension on any sheet. This procedure is recommended for production panels.

Panel fabrication was interrupted after the top plate had been positioned to allow a series of measurements of local compression due to punching holes for insertion of rigid stud fasteners. Thickness of the panel at the clearance holes was measured first before any needle punching. The modified height gage, described in Subsection 2.2, was used for these measurements, with the gage bases resting on the base plate. As mentioned earlier, the outer net face sheet had been omitted on panel layup to allow the electrical indication of surface contact in these visually blind areas.

The hypodermic needle punches were inserted through the insulation, on 24-inch centers, and panel thickness measured in the clearance holes near the needles. Additional needles were then added to give first a 12-inch and then a 6-inch center pattern. Thicknesses near the needles were measured at each pattern to detect any variation in local compression with closer fastener patterns. After measurements on the 6-inch centers had been completed, the needles were removed and panel thickness in the clearance holes was remeasured to determine residual effects of the punching operation.

Results of these measurements are summarized in Table 4-2. It shows that there is essentially no residual effect from punching holes for fasteners, even with holes as close as 6 inches. Detailed measurement data for each of the panels are included for reference in Appendix A.

Table 4-2

EFFECT OF FASTENER INSERTION ON PANEL THICKNESS

System	Average Thickness Change (mil)	Significant Thickness Change with Fastener Pattern
Superfloc	+10.58	None
DAM/Foam	+12.58	None
DAM/Nylon net	-1.71	None
DAME/Tissuglas	-8.04	None
SAME	-15.82	None
DAM/Tissuglas	-19.58	None
DAM/Dexiglas	+3.98	None

4.3 DEMONSTRATION OF DENSITY CONTROL

The completed panels are shown in Figures 4-4 through 4-10. On each panel, a final thickness survey measuring thickness between fastener points, verified that density control had been achieved with the design approach and the fabrication methodology. For reference, the detailed measurement surveys are presented in Appendix A.

While quilting is not visually obvious, the thickness surveys indicate that some quilting does exist and that the panels would perform slightly better than predicted. This is shown in Table 4-3 where average panel thickness between fastener points is compared with design thickness at fastener points. The Superfloc panel was 0.050 inch thicker than the design value between fasteners. The foam panel also showed quilting on the order of 0.050 inch. The Dexiglas, nylon net, and embossed reflector-Tissuglas panels exhibited quitling of 0.040, 0.060, and 0.090 inch, respectively. Note that the panel of SAME was 0.050 inch thinner between fastener points, or more dense than specified. This was because of a change in the height of the embossing pattern on material near

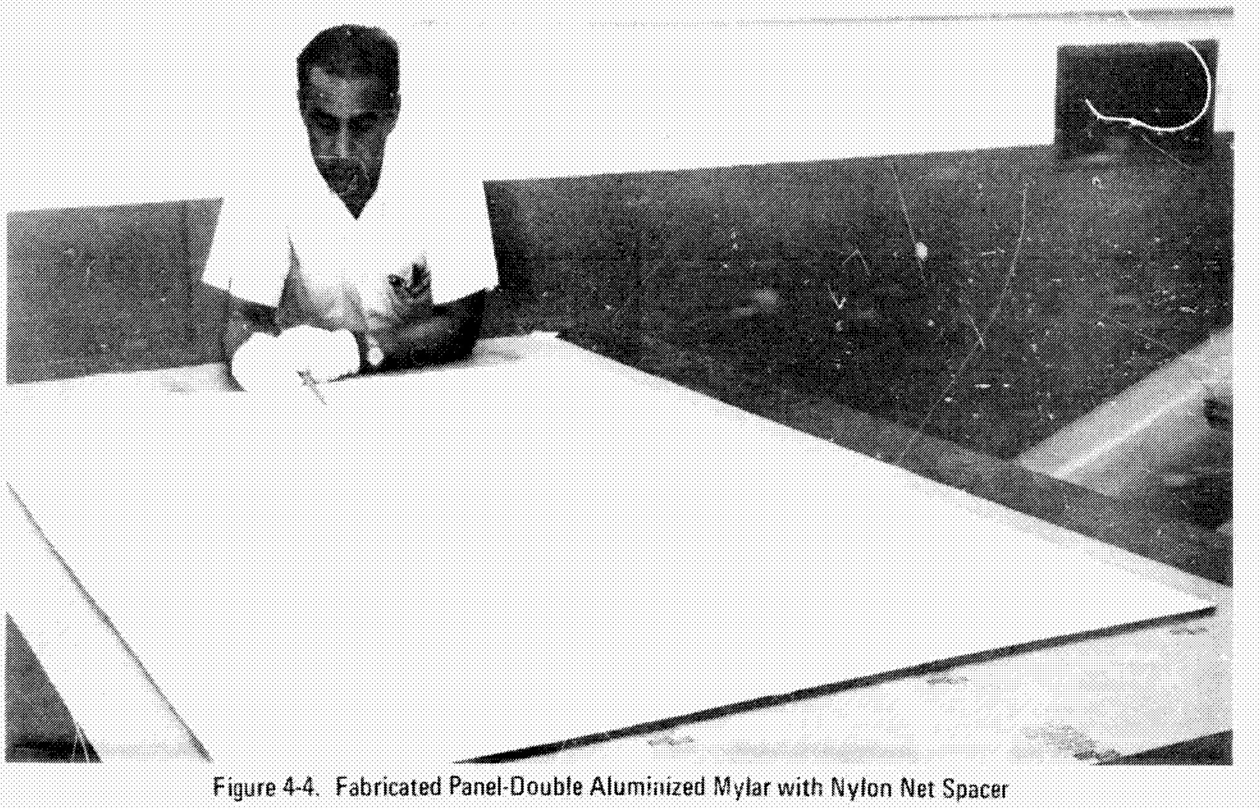


Figure 4-4. Fabricated Panel-Double Aluminized Mylar with Nylon Net Spacer

Figure 4-5. Fabricated Panel-Double Aluminized Mylar With Tissuglas Spacer

Figure 4-6. Fabricated Panel-Double Aluminized Mylar With Foam Spacer

Figure 4-7. Fabricated Panel-Double Aluminized Mylar With Dexiglas Spacer

Figure 4-8. Fabricated Panel-Superfloc

Figure 4-9. Fabricated Panel-Double Aluminized Mylar With Tissuglas Spacer

Figure 4-10. Fabricated Panel-Embossed Single Aluminum Spacer

Table 4-3

SUMMARY OF ASSEMBLED PANEL THICKNESS SURVEYS

System	Design Thickness (in.)	Panel Thickness (in.)	Panel Thickness Standard Deviation, σ (in.)
Superfloc	0.33	0.38	0.0124
DAM/Foam	0.81	0.86	0.0300
DAM/Nylon net	0.22	0.28	0.0091
DAME/Tissuglas	0.25	0.34	0.0798
SAME	0.42	0.37	0.0706
DAM/Tissuglas	0.20	0.21	0.0219
DAM/Dexiglas	0.24	0.28	0.0274

the end of a roll. This completed panel, which would not perform at the design level, suggests that in production processes panels be inspected after layup to reject undersize panels early in the assembly. With an inspection technique based on the automated measuring device developed for earlier measurements, such an inspection is considered feasible.

With the exception of the embossed systems, all panels showed a high degree of uniformity. Table 4-3 also gives the computed mean thickness standard deviation, sigma, for each of the thickness surveys. (Each survey consisted of 110 measurements, yielding a very precise sigma.) Note that the net system was most uniform, with a sigma of 0.009 inch. Superfloc panel uniformity was similar, sigma of 0.012 inch. The DAM/Tissuglas system showed a variation in panel uniformity of 0.022. The Dexiglas and foam panel sigmas were 0.027 and 0.030, respectively. The embossed systems showed the highest degree of nonuniformity, appreciably greater than the other materials, with sigmas of 0.080 and 0.071, respectively, for the embossed reflector-Tissuglas and the singly aluminized Mylar systems. This is due to the material characteristics as discussed in the following section. The nonembossed systems, all with sigmas of 0.030 or less, clearly demonstrate the ability to fabricate uniform density panels repeatably.

4.4 FABRICABILITY OBSERVATIONS

During this effort notes on the fabricability of each system were compiled to aid in material ranking. Time to fabricate was monitored and specific problems with materials were noted, with, when possible, suggested methods to circumvent difficulties. This type of information has not been available previously and would be of assistance to other investigators, reducing duplicate effort. Also an early compilation of potential problem areas indicates where effort should be directed in developing production methods. These notes are reported in Appendix C.

Examination of the notes shows that the embossed systems exhibited extreme variation in embossing height from beginning to end of roll. They also have a further problem. Both embossed materials exhibited a stretched effect; sheets were rippled rather than flat. This distortion carried through the fabrication and can be observed on the embossed panels in Figures 4-9 and 4-10. As shown in Table 4-3, the completed panel thickness varied widely because of this characteristic. Discussion with the supplier indicated that these effects can be expected from currently available materials. It is felt that the embossed systems require further development before they can be considered for a production application.

Discoloration was observed on edges of Tissuglas rolls, and some question exists about the stability of the binder. It is recommended that this be investigated.

It was also felt that the Superfloc system requires further development. Flocing was not uniform in the material used in this study. Since this was the first Superfloc made with 15-gage material it was assumed that this problem is not an inherent characteristic and material used in the study was screened to eliminate any defective area. The most serious drawback with current

Superfloc is the limitation on maximum sheet length – currently at 12 feet. This limitation, if truly fixed, would impose a severe constraint on vehicle insulation design with this material.

4.5 FABRICABILITY RANKING

The new methodology reported herein, which defines a minimum practical density (MPD) for each system permits a more scientific approach to fabricability ranking as well as thermal ranking. The previous practice of relying solely on shop estimates can now be extended to realistically consider fabricability for MNV applications. Of course, as with MPD, the below approach to ranking is general and the method can be applied successfully to other vehicle system applications with different insulation requirements. It can also be extended to new systems which may be developed in the future.

4.5.1 Evaluation Criteria

Evaluation criteria were extended beyond the "ease of fabrication" and material costs used to date. Ease of fabricability is an intangible unless related to a quantitative value, cost to manufacture. Predictability and susceptibility to damage are also considered primary ranking criteria. Material costs are generally small in comparison with overall manufacturing costs and are felt to be only a secondary factor. The ranking criteria used for this study were:

- Primary
  - Fabrication cost
  - Predictability
  - Susceptibility to damage
- Secondary
  - Material cost

4.5.2 Fabrication Cost Ranking

The conventional "ease of fabrication" criterion can now be evaluated in terms of fabrication costs – as measured by time to assemble the required amount of insulation – based on the panel fabrication time measurements noted above. Relative fabrication costs are directly related to the application, to the number of sheets in a panel and the number of panels per blanket. The measured times to assemble the panels were corrected for a learning curve before being used in the ranking.

The resulting ranking of fabrication costs, with lowest numbers indicating preferred systems, is presented in Table 4-4. The numerical ratings shown resulted by assigning the value one to the shortest time and ratioing longer times (higher costs) to this number. This ranking is shown as a three-step process, with the first step a ranking on the basis of time to assembly a reflector-separator pair.

The first step, column one, could be considered comparable to the previous "ease of fabrication" ranking. On this basis, the SAME material would be the leading system. However, when MNV requirements are considered, column two, time to assemble the required number of sheets for an MNV panel, fabrication costs for this system are substantially higher than the other systems because of the higher number of sheets required per panel. This difference is magnified further by the final step, column three, which consider the time to assemble the total number of panels required per blanket (total MNV thickness). Ranking to realistic MNV insulation requirements is substantially different from the previous ranking based on intangible shop estimates as clearly shown by comparing columns one and three. For MNV applications, the three leading systems on the basis of fabrication costs are DAM/Tissuglas, Superfloc, and DAM/nylon net, rated 1.0, 1.1, and 1.7, respectively.

The table can be used for future comparisons also. The time to lay up a reflector-separator pair is valid for defining a fabrication cost ranking for other vehicle system applications with different amounts of required insulation.

4.5.3 Predictability Ranking

Predictability ranking (Table 4-5) was based on uniformity of fabricated panel thickness using the panel fabrication data. The standard deviation, sigma, of the thickness surveys is presented again in the first column; relative ratings based on these data are shown in the second column. Again, as in the above fabrication cost ranking, the relative numerical ratings resulted by assigning the lowest sigma the value one and ratioing the high

Table 4-4

RELATIVE RANKING ON BASIS
OF FABRICATION COSTS

System	Criteria Time to Lay Up a Reflector-Separator Pair	Time To Lay Up an MNV Panel	Time to Lay Up Required Number of Panels
SAME	1.0	4.0	5.7
DAM/Nylon net	1.5	1.6	1.7
DAM/Tissuglas	2.3	1.4	1.0
Superfloc	2.4	1.0	1.1
DAM/Foam	2.6	1.6	2.4
DAME/Tissuglas	2.9	2.0	2.1
DAM/Dexiglas	2.9	1.8	1.9

Table 4-5

RELATIVE RANKING ON BASIS OF PREDICTABILITY

System	Panel Thickness Standard Deviation (σ — inch)	Relative Predictability Ranking
DAM/Nylon net	0.0091	1.0
Superfloc	0.0124	1.4
DAM/Tissuglas	0.0219	2.4
DAM/Foam	0.0300	3.3
DAM/Dexiglas	0.0274	3.0
SAME	0.0706	7.8
DAME/Tissuglas	0.0798	8.8

sigmas to this value. Ranking to this criterion yields DAM/nylon net, Superfloc, and DAM/Tissuglas (rated 1.0, 1.3, and 2.4) followed by the foam and the Dexiglas systems. Embossed systems are least preferred.

4.5.4 Susceptibility to Damage Ranking

Ranking for susceptibility to damage (Table 4-6) was subjective, based on the estimated strength of the separator materials after handling each material. This ranking rates the systems on the potential of damage during handling. The single-component systems were assigned the lowest value, one. The net separator was considered least susceptible to damage and rated 1.2, with foam next, 2.0, followed by Tissuglas, 2.2. Dexiglas was considered the weakest of the separators and was rated 3.0. A more stringent measurement, resistance to degradation due to handling, installation, and other inadvertent compression, if it can be reduced to criteria, would be preferable, but none is known at this time.

Table 4-6

RELATIVE RANKING ON BASIS OF SUSCEPTIBILITY TO DAMAGE

System	Relative Susceptibility to Damage
Superfloc	1.0
SAME	1.0
DAM/Nylon net	1.2
DAM/Foam	2.0
DAM/Tissuglas	2.2
DAME/Tissuglas	2.2
DAM/Dexiglas	3.0

4.5.5 Material Cost Ranking

Material costs ranking was based on figures quoted in Reference 1 for material quantities defined in this study. Price quotes were obtained for the embossed materials which were not included in the referenced work. Here too, the relative ratings (Table 4-7) resulted by ratioing to the lowest figure. The numerical values shown in the table are reduced by a tenth because this criterion is considered secondary to the other criteria. DAM/foam is found to be the least expe· sive system material cost wise and Superfloc the most expensive.

4.5.6 Ranking Study Results

An extensive study would be necessary to further quantize the ranking by applying weighting factors to the separate criteria. This was not felt to be necessary at this time. If pertinent information is developed in the future, appropriate weightings can be applied to the rankings summarized in Table 4-8 to yield a more precise result. To arrive at a recommended fabricability ranking (Table 4-9), the numerical ratings were added in a simple summation,

Table 4-7

RELATIVE RANKING ON BASIS OF MATERIAL COSTS

System	Material Cost ($)	Relative Material Cost Ranking
DAM/Foam	19,992	1
DAM/Dexiglas	35,616	2
DAM/Nylon net	63,504	3
DAM/Tissuglas	69,300	4
SAME	89,994	4
DAME/Tissuglas	113,400	6
Superfloc	131,040	7

Table 4-8

FABRICABILITY RANKING STUDY RESULTS

System	Criteria — Relative Ratings				
	Time to Assemble	Panel Uniformity	Susceptibility to Damage	Material Cost	Additive Rating Summation
DAM/Tissuglas	1.0	2.4	2.2	0.4	6.0
Superfloc	1.1	1.4	1.0	0.7	4.2
DAM/Nylon Net	1.7	1.0	1.2	0.3	4.2
DAM/Dexiglas	1.9	3.0	3.0	0.2	8.1
DAME/Tissuglas	2.1	8.8	2.2	0.6	13.7
DAM/Foam	2.4	3.3	2.0	0.1	7.8
SAME	5.7	7.8	1.0	0.4	14.9

Table 4-9
RECOMMENDED FABRICABILITY RANKING

Ranking Based on Study Results	
4.2	Superfloc
4.2	DAM/Nylon net
6.0	DAM/Tissuglas
7.8	DAM/Foam
8.1	DAM/Dexiglas
13.7	DAME/Tissuglas
14.9	SAME

with lowest numbers indicating the preferred systems. Superfloc, and the DAM/nylon net systems share the leading position with the lowest rating of 4.2. The DAM/Tissuglas system with a total of 6.0 is ranked third. The foam and Dexiglas separator systems rank fourth and fifth with ratings of 7.8 and 8.1. The embossed systems are least preferred with ratings of 13.7 and 14.9 with the single aluminized mylar rated lowest.

Section 5
SELECTION OF THE MOST PROMISING SYSTEMS

Sections 2, 3, and 4 discussed the results of the insulation density control, thermal ranking, and fabrication ranking studies. These results lead to the focal point of the entire effort, selection of the three most promising insulation systems for MNV application from the seven evaluated. Thermal and fabrication rankings were subsequently integrated into an overall recommended ranking. Final systems selection was then accomplished during the scheduled selection meeting at MSFC.

5.1 INTEGRATION OF THERMAL AND FABRICABILITY RANKINGS

Thermal performance rankings or fabricability rankings are, by themselves, inadequate for selection of the best vehicle insulation system. The thermal performance criteria (vehicle weight penalty) ignores the shop's ability to fabricate the system and the cost and difficulty involved in the fabrication. Conversely, shop evaluations are devoid of the system's thermal performance. Thus it is desirous to find a common denominator to the two types of rankings so that a single, clear, quantitative ranking, and hence system selection, can be made.

A basis of equivalence was built into the thermal and fabrication studies discussed in Sections 3 and 4. The theoretical heat transfer analysis determined the optimum amount of insulation for each system for the baseline MNV flying the baseline mission.

The results of the theoretical analyses (amount of insulation) were then used to generate the fabricability and cost data for use in fabricability ranking. Thus the fabricability ranking is based upon the equivalent optimum insulation systems.

A firm, quantitative criteria for use in integrating the thermal and fabricability rankings did not become apparent during the study. A tradeoff between vehicle performance and cost is involved and development of quantitative criteria depends upon the firmness of vehicle specifications and degree of emphasis to be placed on cost. Both factors, as related to the MNV, appear uncertain at present. Therefore, it was necessary to select a nonquantitative approach. The criteria chosen was that the thermal ranking would provide the basis for selection, except in cases where the material ranked low in fabricability.

5.1.1 Materials Ranked on the Basis of Equal Level of Development

The thermal and fabricability rankings of the seven systems evaluated in the study are listed in Table 5-1. The MNV thermal weight penalty associated with each insulation material is shown. The numerical fabrication ranking factor, discussed in Section 4, is also shown.

Table 5-1

MATERIALS RANKED ON BASIS OF EQUAL LEVEL OF DEVELOPMENT

Thermal Ranking	Penalty (lbs)		Recommended Fabricability Ranking		Combined Ranking
Superfloc	305	(4.2)	Superfloc	1.	Superfloc
DAM/Tissuglas	550	(4.2)	DAM/Nylon net	2.	DAM/Tissuglas
DAME/Tissuglas	990	(6.0)	DAM/Tissuglas	3.	DAM/Nylon net
DAM/Dexiglas	1920	(7.8)	DAM/Foam		
DAM/Nylon net	2000	(8.1)	DAM/Dexiglas		
SAME	2050	(13.7)	DAME/Tissuglas		
DAM/Foam	3900	(14.9)	SAME		

It will be noted that Superfloc is clearly indicated to be the most promising system. DAM/Tissuglas was selected for second place. Its system weight penalty is only about one-fourth that of the net system which ranks somewhat higher in fabricability. For third choice, the next possible candidate, DAME/Tissuglas, rates very low from the standpoint of fabricability and hence was rejected. The next candidates, the Dexiglas and net systems, are about equivalent thermally but the net system ranks higher in fabricability. It was selected as the third most promising system.

5.1.2 Materials Ranked on the Basis of Unequal Level of Development

If all of the candidate systems were at the same level of development the recommended top three candidates would be as shown in Table 5-1. However, as discussed in Section 4, it was felt that this was not the case. The systems were further ranked to a development criteria (Table 5-2). This ranking was on an empirical basis; the net, foam, and Dexiglas systems were rated 1, highest level of development. Superfloc was rated 2, and the embossed materials, 3. Tissuglas, with some question about the stability of the material, was rated 1.2. These ratings were applied as modifiers to the fabricability study ranking (Table 5-1). The results of this modification are presented in Table 5-3. There was no effect in the relative ranking of the embossed materials, which were least preferred initially. Superfloc, however, is reduced in rank to fifth place. The thermal and modified fabricability rankings are summarized in Table 5-4. It shows that DAM/Tissuglas is clearly a high ranking system and should be included as one of the three selections. The embossed systems appear undesirable for further consideration. Also, rejection of Dexiglas is believed warranted due to its extreme fragility and the selection of a better similar system, Tissuglas, as a candidate. Two choices had to be made from among the three remaining systems, Superfloc, net, and foam. The Superfloc was rejected because of its present availability in only 12-foot lengths, too short for practical vehicle application.

Table 5-2

RELATIVE RANKING ON BASIS OF LEVEL OF DEVELOPMENT

System	Relative Development Ranking
DAM/Nylon net	1.0
DAM/Foam	1.0
DAM/Dexiglas	1.0
DAM/Tissuglas	1.2
Superfloc	2.0
SAME	3.0
DAME/Tissuglas	3.2

Table 5-3

MODIFIED FABRICABILITY RANKING

Ranking Based on Study Results	Recommended Ranking Considering Level of Development
(4.2) Superfloc	(4.2) DAM/Nylon net
(4.2) DAM/Nylon net	(7.2) DAM/Tissuglas
(6.0) DAM/Tissuglas	(7.8) DAM/Foam
(7.8) DAM/Foam	(8.2) DAM/Dexiglas
(8.1) DAM/Dexiglas	(8.4) Superfloc
(13.7) DAME/Tissuglas	(44.2) DAME/Tissuglas
(14.9) SAME	(44.7) SAME

Table 5-4

MATERIALS RANKED ON BASIS OF UNEQUAL LEVEL OF DEVELOPMENT

Thermal Ranking	Weight Penalty (lb)	Modified Fabricability Ranking		Recommended Selection
Superfloc	305	(4.2)	DAM/Nylon net	1. DAM/Tissuglas
DAM/Tissuglas	550	(7.2)	DAM/Tissuglas	2. DAM/Nylon net
DAME/Tissuglas	900	(7.8)	DAM/Foam	3. DAM/Foam
DAM/Dexiglas	1920	(8.2)	DAM/Dexiglas	
DAM/Nylon net	2000	(8.4)	Superfloc	
SAME	2050	(44.2)	DAME/Tissuglas	
DAM/Foam	3900	(44.7)	SAME	

5.2 MSFC MATERIAL SELECTION MEETING

Final material selection was accomplished with NASA-MSFC concurrence on June 6, 1969. Discussion indicated that the degree of development criteria should not be applied at this time. The three systems selected are those in Table 5-1: Superfloc, DAM/Tissuglas, and DAM/Nylon net. These three systems will be evaluated further in the study to select one system for MNV design.

REFERENCES

1. Investigations Regarding Development of a High-Performance Insulation System Final Report. Contract NAS8-20758, Lockheed Missiles & Space Co., Sunnyvale, California, 1968.

2. Investigation of High-Performance Application Problems. First Quarterly Report, DAC-63250, Contract NAS-8-21400, McDonnell Douglas Astronautics Company, 20 April 1969.

3. E.L. Bombara. Reliability of Compliance with One Sided Specification Limits when Data is Normally Distributed. ARGMA-TR-2B1R, Army Rocket and Guided Missile Agency, 15 September 1961.

Appendix A
INSULATION PANEL MEASUREMENT DATA

This appendix presents all measurements taken and used in the density study described in this report. These measurements provide the raw data for any desired future statistical analyses. A larger statistical sample may be formulated by adding new data as they evolve.

Figure A-1 and Tables A-1 through A-9 present the data used for the statistical analyses in the study. Figure A-1 shows the nine locations where thickness measurements were made on the stacked, 2- by 4-foot insulation panels. The error in the height gage used to make panel thickness measurements is shown in Table A-1. This error is the maximum deflection in the bar, connecting the two gages. The data indicate that a height measurement at a point between the two gages (locations 2, 5, and 8, Figure A-1) is in error by about 0.005 inch, maximum, or 1% of a 0.5-inch-thick panel. Tables A-2 through A-8 present all the thickness measurements used as the basis for the statistical determination of minimum practical density. Table A-9 lists settling data taken during the study; the panel thickness measurements made after discrete intervals of time.

Tables A-10 through A-18 list all measurements used to evaluate the fabricated 4- by 5-foot panels. Measurements were made in the locations shown in the tables. Table A-10 shows the flatness deviation from a true horizontal plane of the fabrication tooling bottom and top plates. The maximum base-plate and top-plate deviation from a mean horizontal plane is ±0.013 in. Tables A-11 through A-18 present the measurements made of panel thickness after fabrication and assembly was complete. Table A-18 shows the changes in panel thickness, at the point of punching, after holes were punched in the panels on 24-, 12- and 6-inch centers.

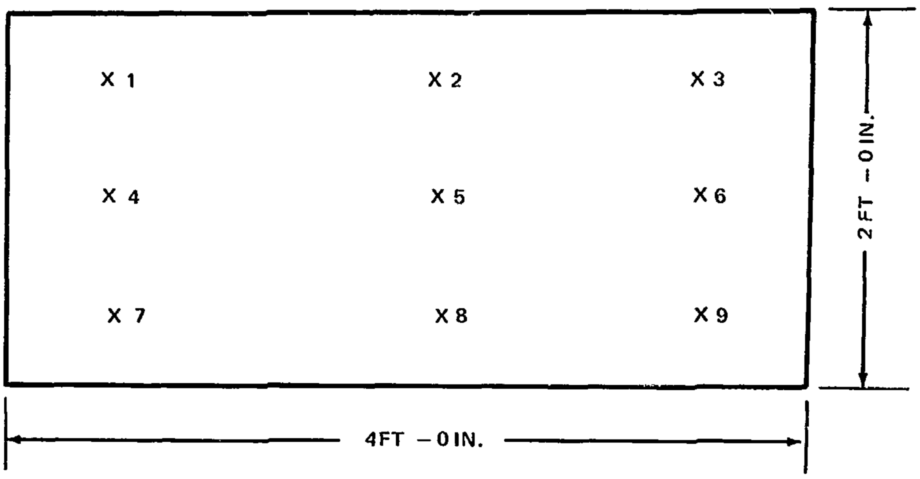


Figure A-1. Panel Thickness Measurement Locations

Table A-1

HEIGHT GAGE MEASUREMENT ERROR

Station (inches)	Deflection (inches)
0	0
10	0.0020
15	0.0035
20	0.0050
25	0.0052
30	0.0040
35	0.0025
40	0.001
47	0

Table A-2

PANEL THICKNESS MEASUREM
(Inches)

Material: Superfloc

Initial Stacking

Measurement Location	10 Sheets					15 Sheets				
1	0.367	0.423	0.420	0.446	0.466	0.568	0.666	0.630	0.690	0.660
2	0.403	0.487	0.445	0.458	0.466	0.587	0.729	0.663	0.673	0.674
3	0.383	0.483	0.462	0.436	0.452	0.552	0.715	0.639	0.646	0.662
4	0.364	0.461	0.403	0.482	0.485	0.592	0.685	0.608	0.699	0.659
5	0.391	0.495	0.450	0.478	0.459	0.578	0.720	0.640	0.667	0.685
6	0.406	0.449	0.438	0.458	0.497	0.595	0.705	0.613	0.678	0.691
7	0.396	0.447	0.432	0.485	0.444	0.544	0.680	0.617	0.660	0.638
8	0.440	0.425	0.478	0.493	0.476	0.593	0.631	0.610	0.665	0.667
9	0.397	0.445	0.440	0.420	0.473	0.528	0.637	0.636	0.652	0.624

Restacked

Measurement Location	10 Sheets					15 Sheets				
1	0.383	0.484	0.472	0.464	0.421	0.581	0.606	0.646	0.676	0.644
2	0.426	0.450	0.436	0.463	0.432	0.614	0.633	0.645	0.644	0.667
3	0.451	0.444	0.446	0.436	0.446	0.615	0.678	0.686	0.642	0.610
4	0.418	0.453	0.449	0.433	0.431	0.628	0.663	0.675	0.623	0.652
5	0.439	0.452	0.435	0.430	0.454	0.634	0.629	0.626	0.631	0.596
6	0.436	0.446	0.443	0.437	0.488	0.624	0.637	0.649	0.640	0.655
7	0.431	0.450	0.419	0.405	0.469	0.590	0.579	0.657	0.614	0.677
8	0.409	0.412	0.462	0.388	0.418	0.632	0.624	0.643	0.593	0.624
9	0.391	0.446	0.452	0.419	0.442	0.615	0.606	0.660	0.603	0.656

Table A-2

CKNESS MEASUREMENTS
(Inches)

itial Stacking

s		20 Sheets					Stacked Panels: Total Sheets			
							40	60	80	100
0.690	0.660	0.735	0.831	0.845	0.886	0.855	1.389	1.813	2.196	2.597
0.673	0.674	0.772	0.898	0.871	0.879	0.879	1.381	1.875	2.309	2.712
0.646	0.662	0.798	0.922	0.844	0.850	0.897	1.400	1.840	2.327	2.650
0.699	0.659	0.747	0.831	0.836	0.887	0.848	1.414	1.910	2.343	2.805
0.667	0.685	0.774	0.897	0.799	0.872	0.878	1.421	1.903	2.387	2.798
0.678	0.691	0.769	0.853	0.791	0.885	0.876	1.438	1.957	2.507	2.865
0.660	0.638	0.701	0.811	0.755	0.874	0.841	1.290	1.804	2.200	2.596
0.665	0.667	0.737	0.830	0.768	0.887	0.839	1.313	1.726	2.207	2.594
0.652	0.624	0.727	0.830	0.778	0.855	0.800	1.376	1.823	2.214	2.653

– Restacked

s		20 Sheets					Stacked Panels: Total Sheets			
							40	60	80	100
0.676	0.644	0.754	0.800	0.834	0.813	0.910	1.361	1.907	2.322	2.644
0.644	0.667	0.806	0.805	0.855	0.823	0.853	1.267	1.870	2.297	2.705
0.642	0.610	0.824	0.848	0.878	0.833	0.761	1.209	1.752	2.243	2.686
0.623	0.652	0.809	0.828	0.814	0.791	0.850	1.380	1.915	2.356	2.811
0.631	0.596	0.806	0.812	0.818	0.785	0.835	1.289	1.884	2.297	2.748
0.640	0.655	0.857	0.857	0.851	0.807	0.839	1.338	1.945	2.414	2.798
0.614	0.677	0.780	0.784	0.793	0.759	0.857	1.267	1.773	2.229	2.636
0.593	0.624	0.798	0.826	0.794	0.590	0.852	1.237	1.729	2.235	2.613
0.603	0.656	0.817	0.800	0.831	0.763	0.847	1.177	1.698	2.262	2.645

FOLDOUT FRAME

Table A-3

PANEL THICKNESS MEAS

(Inches)

Material: Embossed Single Aluminized Mylar (SAME)

Initial Stacking

Measurement Location	15 Sheets					25 Sheets				
1	0.266	0.286	0.178	0.311	0.298	0.401	0.191	0.262	0.394	0.378
2	0.192	0.233	0.237	0.261	0.375	0.371	0.314	0.361	0.381	0.331
3	0.310	0.263	0.285	0.281	0.393	0.473	0.426	0.444	0.412	0.353
4	0.378	0.200	0.153	0.290	0.397	0.370	0.274	0.320	0.525	0.353
5	0.287	0.332	0.234	0.363	0.565	0.435	0.431	0.569	0.465	0.470
6	0.317	0.245	0.261	0.364	0.344	0.455	0.317	0.387	0.549	0.444
7	0.239	0.252	0.160	0.215	0.187	0.391	0.295	0.245	0.3[illegible]2	0.262
8	0.224	0.211	0.209	0.236	0.185	0.349	0.309	0.451	0.360	0.388
9	0.243	0.273	0.226	0.287	0.295	0.381	0.363	0.369	0.379	0.414

Restacked

Measurement Location	15 Sheets					25 Sheets				
1	0.217	0.336	0.201	0.381	0.212	0.237	0.411	0.326	0.555	0.337
2	0.183	0.293	0.360	0.215	0.257	0.338	0.477	0.448	0.396	0.420
3	0.195	0.257	0.193	0.216	0.215	0.305	0.450	0.306	0.391	0.285
4	0.276	0.336	0.175	0.240	0.236	0.310	0.577	0.285	0.440	0.353
5	0.195	0.476	0.240	0.373	0.396	0.323	0.760	0.434	0.545	0.529
6	0.346	0.304	0.265	0.198	0.279	0.430	0.354	0.291	0.470	0.323
7	0.240	0.242	0.161	0.199	0.184	0.287	0.275	0.268	0.382	0.306
8	0.206	0.213	0.192	0.221	0.164	0.277	0.315	0.275	0.320	0.294
9	0.230	0.237	0.188	0.224	0.157	0.322	0.337	0.290	0.419	0.275

Table A-3

NEL THICKNESS MEASUREMENTS
(Inches)

Initial Stacking

Sheets			35 Sheets					Stacked Panels: Total Sheets			
								70	105	140	175
0.262	0.394	0.378	0.588	0.614	0.293	0.336	0.462	0.554	0.754	0.975	1.195
0.361	0.381	0.331	0.584	0.475	0.339	0.438	0.536	0.554	0.724	1.095	1.350
0.444	0.412	0.353	0.626	0.487	0.402	0.500	0.448	0.693	0.925	1.232	1.417
0.320	0.525	0.353	0.466	0.442	0.345	0.427	0.400	0.539	0.760	0.950	1.325
0.569	0.465	0.470	0.585	0.514	0.451	0.593	0.753	0.540	0.725	1.108	1.302
0.387	0.549	0.444	0.584	0.502	0.459	0.465	0.543	0.661	1.005	1.132	1.559
0.245	0.322	0.262	0.395	0.426	0.215	0.370	0.418	0.562	0.746	1.000	1.340
0.451	0.360	0.388	0.502	0.403	0.333	0.499	0.490	0.551	0.735	1.007	1.336
0.369	0.379	0.414	0.456	0.433	0.423	0.499	0.474	0.701	1.030	1.207	1.565

Restacked

Sheets			35 Sheets					Stacked Panels: Total Sheets			
								70	105	140	175
0.326	0.555	0.337	0.402	0.376	0.350	0.427	0.406	0.667	0.880	1.110	1.322
0.448	0.396	0.420	0.437	0.448	0.490	0.270	0.462	0.608	0.852	1.068	1.238
0.306	0.391	0.285	0.408	0.465	0.406	0.320	0.433	0.643	0.872	1.183	1.346
0.285	0.440	0.353	0.440	0.395	0.363	0.318	0.399	0.565	0.809	1.022	1.258
0.434	0.545	0.529	0.642	0.462	0.538	0.526	0.429	0.648	0.790	0.955	1.238
0.291	0.470	0.323	0.550	0.435	0.418	0.390	0.431	0.635	0.931	1.221	1.412
0.268	0.382	0.306	0.396	0.362	0.340	0.277	0.367	0.601	0.840	1.040	1.286
0.275	0.320	0.294	0.453	0.438	0.315	0.293	0.368	0.554	0.770	0.980	1.204
0.290	0.419	0.275	0.462	0.429	0.377	0.306	0.384	0.707	0.911	1.089	1.352

FOLDOUT FRAME

Table A-4

PANEL THICKNESS MEASUREM

(Inches)

Material: Double Aluminized Mylar (Foam)

Initial Stacking

Measurement Location	17 Sheets					20 Sheets				
1	0.811	0.825	0.806	0.803	0.794	0.953	0.992	0.993	0.942	0.957
2	0.795	0.807	0.825	0.823	0.816	0.982	0.978	0.969	1.035	0.928
3	0.836	0.823	0.797	0.824	0.854	0.969	0.979	0.944	0.940	0.964
4	0.803	0.854	0.825	0.856	0.834	1.003	0.985	0.968	0.975	0.985
5	0.929	0.857	0.917	0.884	0.854	0.927	1.002	1.003	0.996	1.014
6	0.874	0.846	0.848	0.826	0.841	0.958	0.988	0.994	0.995	0.990
7	0.874	0.800	0.840	0.836	0.815	1.007	0.962	1.007	0.974	0.978
8	0.828	0.827	0.847	0.847	0.828	0.953	0.945	0.995	0.982	0.975
9	0.812	0.806	0.844	0.809	0.811	0.928	0.941	0.961	0.957	0.988

Restacked

Measurement Location	17 Sheets					20 Sheets				
1	0.861	0.770	0.797	0.837	0.762	0.965	0.972	0.910	0.973	0.925
2	0.840	0.803	0.793	0.805	0.727	0.983	0.956	0.939	0.971	0.935
3	0.850	0.830	0.808	0.812	0.773	1.006	1.035	0.957	0.958	0.947
4	0.875	0.830	0.820	0.815	0.827	1.004	1.008	0.959	0.965	0.999
5	0.879	0.859	0.819	0.857	0.839	0.998	0.999	0.954	0.980	0.958
6	0.848	0.884	0.852	0.828	0.902	0.974	1.030	0.972	0.980	0.969
7	0.886	0.837	0.819	0.831	0.834	1.035	1.020	0.958	0.985	0.962
8	0.900	0.855	0.787	0.854	0.808	0.960	1.003	0.915	0.982	0.949
9	0.819	0.825	0.802	0.809	0.871	0.985	0.985	0.925	0.972	0.929

Table A-4

'HICKNESS MEASUREMENTS
(Inches)

— Initial Stacking

·ets			23 Sheets					Stacked Panels: Total Sheets			
								46	69	92	115
3	0.942	0.957	1.061	1.100	1.067	1.077	1.080	2.038	3.080	4.069	5.038
9	1.035	0.928	1.091	1.150	1.091	1.135	1.092	2.080	3.073	4.114	5.053
4	0.940	0.964	1.115	1.149	1.087	1.097	1.117	2.079	3.046	4.094	5.026
8	0.975	0.985	1.116	1.129	1.111	1.190	1.131	2.192	3.182	4.185	5.177
3	0.996	1.014	1.129	1.176	1.115	1.152	1.150	2.161	3.185	4.229	5.267
4	0.995	0.990	1.153	1.153	1.136	1.168	1.137	2.168	3.145	4.220	5.178
7	0.974	0.978	1.100	1.125	1.128	1.147	1.094	2.101	3.101	4.100	5.037
5	0.982	0.975	1.140	1.111	1.094	1.169	1.111	2.100	3.111	4.110	5.090
1	0.957	0.988	1.075	1.114	1.094	1.098	1.117	2.088	3.045	4.087	5.040

——Restacked

·ets			23 Sheets					Stacked Panels: Total Sheets			
								46	69	92	115
0	0.973	0.925	1.125	1.111	1.043	1.105	1.019	2.084	3.088	4.062	5.105
9	0.971	0.935	1.110	1.143	1.061	1.109	1.056	2.095	3.057	4.095	5.092
7	0.958	0.947	1.145	1.118	1.069	1.097	1.012	2.075	3.035	4.105	5.081
9	0.965	0.999	1.162	1.190	1.077	1.118	1.089	2.152	3.185	4.126	5.158
4	0.980	0.958	1.180	1.155	1.106	1.151	1.089	2.221	3.278	4.223	5.245
2	0.980	0.969	1.137	1.156	1.071	1.118	1.121	2.182	3.173	4.252	5.234
8	0.985	0.962	1.210	1.100	1.070	1.141	1.110	2.136	3.104	4.089	5.036
5	0.982	0.949	1.245	1.134	1.081	1.117	1.084	2.122	3.111	4.125	5.111
5	0.972	0.929	1.142	1.125	1.046	1.127	1.065	2.134	3.108	4.092	5.100

FOLDOUT FRAME

Table A-5

PANEL THICKNESS MEASUREMI
(Inches)

Material: Double Aluminized Mylar (Nylon Net)

Initial Stacking

Measurement Location	20 Sheets					30 Sheets				
1	0.260	0.239	0.258	0.283	0.241	0.364	0.382	0.543	0.385	0.468
2	0.301	0.302	0.285	0.346	0.319	0.421	0.421	0.458	0.420	0.474
3	0.364	0.291	0.284	0.355	0.273	0.498	0.400	0.506	0.425	0.508
4	0.275	0.272	0.279	0.332	0.388	0.414	0.385	0.409	0.407	0.528
5	0.346	0.355	0.338	0.403	0.573	0.482	0.491	0.450	0.477	0.604
6	0.331	0.314	0.286	0.292	0.469	0.507	0.526	0.510	0.433	0.508
7	0.241	0.278	0.270	0.258	0.295	0.365	0.411	0.385	0.381	0.390
8	0.344	0.302	0.287	0.329	0.363	0.491	0.420	0.435	0.412	0.406
9	0.710	0.328	0.276	0.275	0.314	0.511	0.455	0.423	0.384	0.416

Restacked

Measurement Location	20 Sheets					30 Sheets				
1	0.237	0.235	0.258	0.270	0.300	0.352	0.446	0.429	0.366	0.385
2	0.271	0.305	0.332	0.335	0.266	0.417	0.548	0.440	0.424	0.374
3	0.390	0.295	0.304	0.260	0.335	0.473	0.448	0.398	0.452	0.419
4	0.432	0.290	0.259	0.248	0.336	0.498	0.491	0.397	0.395	0.413
5	0.477	0.373	0.317	0.349	0.354	0.565	0.554	0.477	0.570	0.477
6	0.306	0.333	0.346	0.318	0.3[illegible]0	0.440	0.449	0.498	0.499	0.454
7	0.259	0.272	0.249	0.254	0.280	0.378	0.351	0.386	0.381	0.428
8	0.336	0.324	0.314	0.343	0.314	0.451	0.441	0.430	0.414	0.397
9	0.287	0.349	0.268	0.269	0.280	0.461	0.411	0.412	0.404	0.392

FOLDOUT FRAME

Table A-5

. THICKNESS MEASUREMENTS
(Inches)

—— Initial Stacking ——

Sheets		
543	0.385	0.468
458	0.420	0.474
506	0.425	0.508
409	0.407	0.528
450	0.477	0.604
510	0.433	0.508
385	0.381	0.390
435	0.412	0.406
423	0.384	0.416

40 Sheets				
0.492	0.519	0.486	0.521	0.492
0.544	0.516	0.537	0.537	0.523
0.670	0.504	0.597	0.610	0.504
0.580	0.575	0.521	0.546	0.556
0.627	0.681	0.683	0.569	0.760
0.645	0.604	0.606	0.587	0.534
0.592	0.577	0.523	0.524	0.487
0.572	0.615	0.527	0.592	0.542
0.610	0.568	0.551	0.520	0.527

Stacked Panels: Total Sheets			
80	120	160	200
0.896	1.322	1.763	2.157
0.928	1.342	1.823	2.199
0.918	1.345	1.760	2 237
0.919	1.358	1.768	2.348
1.030	1.403	1.840	2.270
0.933	1.347	1.780	2.240
0.890	1.327	1.745	2.237
0.973	1.348	1.796	2.265
0.922	1.346	1.799	2.262

—— Restacked ——

Sheets		
429	0.366	0.385
440	0.424	0.374
398	0.452	0.419
397	0.395	0.413
477	0.570	0.477
498	0.499	0.454
386	0.381	0.428
430	0.414	0.397
412	0.404	0.392

40 Sheets				
0.493	0.546	0.477	0.523	0.487
0.521	0.637	0.540	0.550	0.482
0.618	0.538	0.557	0.548	0.546
0.631	0.613	0.492	0.541	0.485
0.774	0.747	0.536	0.646	0.513
0.626	0.603	0.548	0.561	0.547
0.523	0.501	0.479	0.482	0.481
0.636	0.642	0.524	0.565	0.559
0.686	0.577	0.513	0.531	0.498

Stacked Panels: Total Sheets			
80	120	160	200
0.935	1.330	1.800	2.175
0.935	1.365	1.779	2.190
0.970	1.416	1.801	2.230
0.949	1.389	1.816	2.279
0.940	1.433	1.878	2.323
0.997	1.447	1.896	2.307
0.940	1.374	1.791	2.187
0.947	1.376	1.793	2.198
0.990	1.398	1.806	2.310

FOLDOUT FRAME

Table A-6

PANEL THICKNESS MEASUREM

(Inches)

Material: Double Aluminized Mylar (Tissuglas)

Initial Stacking

Measurement Location	20 Sheets					30 Sheets				
1	0.429	0.297	0.339	0.423	0.336	0.356	0.516	0.488	0.379	0.516
2	0.387	0.394	0.404	0.409	0.364	0.498	0.518	0.429	0.498	0.463
3	0.381	0.393	0.320	0.385	0.365	0.534	0.520	0.437	0.388	0.462
4	0.334	0.477	0.507	0.408	0.427	0.539	0.476	0.581	0.397	0.469
5	0.355	0.545	0.564	0.415	0.533	0.540	0.624	0.514	0.433	0.816
6	0.344	0.415	0.581	0.379	0.373	0.508	0.571	0.589	0.434	0.600
7	0.373	0.300	0.398	0.320	0.275	0.369	0.493	0.428	0.385	0.400
8	0.345	0.315	0.416	0.325	0.297	0.438	0.477	0.451	0.494	0.445
9	0.357	0.349	0.411	0.352	0.302	0.466	0.487	0.445	0.453	0.454

Restacked

Measurement Location	20 Sheets					30 Sheets				
1	0.300	0.393	0.419	0.489	0.638	0.388	0.451	0.538	0.629	0.505
2	0.366	0.345	0.429	0.394	0.553	0.388	0.444	0.536	0.576	0.649
3	0.521	0.403	0.393	0.372	0.563	0.511	0.421	0.497	0.506	0.557
4	0.537	0.567	0.488	0.431	0.596	0.523	0.632	0.636	0.853	0.692
5	0.375	0.657	0.454	0.521	0.660	0.421	0.700	0.777	0.908	0.870
6	0.404	0.563	0.484	0.435	0.611	0.498	0.678	0.686	0.759	0.815
7	0.390	0.456	0.356	0.275	0.464	0.497	0.562	0.486	0.568	0.640
8	0.394	0.446	0.378	0.390	0.476	0.439	0.611	0.506	0.674	0.663
9	0.398	0.436	0.366	0.313	0.507	0.411	0.577	0.475	0.569	0.583

FOLDOUT FRAME

Table A-6

THICKNESS MEASUREMENTS
(Inches)

Initial Stacking

Sheets			40 Sheets					Stacked Panels: Total Sheets			
								80	120	160	200
.488	0.379	0.516	0.640	0.627	0.612	0.543	0.694	0.715	0.965	1.337	1.608
.429	0.498	0.463	0.645	0.642	0.763	0.578	0.566	0.713	1.010	1.225	1.608
.437	0.388	0.462	0.688	0.671	0.673	0.576	0.541	0.808	1.090	1.313	1.577
.581	0.397	0.469	0.697	0.793	0.877	0.657	0.748	0.695	1.000	1.352	1.737
.514	0.433	0.816	0.825	0.865	0.891	0.718	0.885	0.812	1.108	1.383	1.761
.589	0.434	0.600	0.780	0.756	0.890	0.644	0.715	0.780	1.068	1.415	1.751
.428	0.385	0.400	0.697	0.710	0.576	0.567	0.584	0.833	1.000	1.350	1.700
.451	0.494	0.44[illegible]	0.643	0.752	0.575	0.734	0.709	0.883	1.030	1.356	1.696
.445	0.453	0.454	0.691	0.693	0.636	0.521	0.610	0.750	1.037	1.407	1.705

Restacked

Sheets			40 Sheets					Stacked Panels: Total Sheets			
								80	120	160	200
.538	0.629	0.505	0.571	0.621	0.722	0.693	0.686	0.761	1.019	1.283	1.552
.536	0.576	0.649	0.606	0.647	0.675	0.682	0.670	0.770	0.962	1.250	1.585
.497	0.506	0.557	0.583	0.558	0.700	0.590	0.666	0.757	0.987	1.236	1.570
.636	0.853	0.692	0.707	0.800	0.936	0.944	0.814	0.888	1.150	1.477	1.747
.777	0.908	0.870	0.679	0.899	1.030	0.920	0.852	0.880	1.060	1.400	1.753
.686	0.759	0.815	0.661	0.795	0.848	0.896	0.805	0.826	1.025	1.360	1.794
.486	0.568	0.640	0.664	0.688	0.669	0.659	0.606	0.951	1.207	1.381	1.739
.506	0.674	0.663	0.561	0.715	0.665	0.686	0.722	0.795	1.035	1.416	1.752
.475	0.569	0.583	0.664	0.665	0.600	0.616	0.683	0.861	1.175	1.450	1.690

FOLDOUT FRAME

Table A-7

PANEL THICKNESS MEASUREM

(Inches)

Material: Double Aluminized Mylar (Dexiglas)

Initial Stacking

Measurement Location	20 Sheets					26 Sheets				
1	0.351	0.352	0.400	0.374	0.379	0.488	0.655	0.620	0.492	0.578
2	0.370	0.348	0.480	0.468	0.391	0.555	0.557	0.568	0.594	0.606
3	0.385	0.368	0.500	0.469	0.450	0.580	0.662	0.633	0.563	0.605
4	0.337	0.376	0.433	0.558	0.333	0.495	0.657	0.647	0.573	0.568
5	0.319	0.433	0.512	0.579	0.355	0.535	0.614	0.710	0.618	0.507
6	0.387	0.585	0.508	0.365	0.340	0.548	0.629	0.504	0.490	0.466
7	0.277	0.443	0.525	0.399	0.475	0.544	0.658	0.706	0.575	0.590
8	0.262	0.465	0.533	0.395	0.395	0.488	0.682	0.571	0.580	0.477
9	0.399	0.455	0.600	0.401	0.409	0.533	0.641	0.503	0.445	0.550

Restack

Measurement Location	20 Sheets					26 Sheets				
1	0.606	0.721	0.606	0.647	0.724	0.925	1.052	0.811	0.822	0.674
2	0.545	0.500	0.665	0.518	0.532	0.780	0.696	0.715	0.635	0.685
3	0.631	0.631	0.757	0.609	0.490	0.691	0.733	0.921	0.786	0.650
4	0.389	0.634	0.485	0.514	0.537	0.498	0.692	0.611	0.564	0.700
5	0.665	0.663	0.543	0.503	0.587	0.708	0.718	0.688	0.734	0.718
6	0.650	0.650	0.555	0.486	0.417	0.626	0.706	0.692	0.636	0.592
7	0.498	0.637	0.470	0.578	0.515	0.750	0.788	0.747	0.849	0.652
8	0.510	0.531	0.523	0.590	0.550	0.539	0.569	0.641	0.675	0.642
9	0.632	0.722	0.715	0.665	0.575	0.739	0.808	0.947	0.669	0.681

Table A-7

'HICKNESS MEASUREMENTS
(Inches)

— Initial Stacking

ʰeets			32 Sheets					Stacked Panels: Total Sheets			
								64	96	128	160
620	0.492	0.578	0.772	0.757	0.836	0.566	0.785	1.142	1.301	1.991	2.247
568	0.594	0.606	0.747	0.696	0.673	0.667	0.795	1.075	1.446	1.882	2.259
633	0.563	0.605	0.635	0.725	0.785	0.739	0.696	1.096	1.424	1.839	2.091
647	0.573	0.568	0.665	0.745	0.820	0.618	0.616	1.118	1.428	1.821	2.150
710	0.618	0.507	0.681	0.745	0.709	0.689	0.620	1.006	1.652	1.834	2.276
504	0.490	0.466	0.617	0.753	0.594	0.631	0.615	0.840	1.269	1.608	2.000
706	0.575	0.590	0.715	0.773	0.723	0.601	0.632	0.988	1.365	1.743	2.208
571	0.580	0.477	0.645	0.825	0.673	0.627	0.557	1.114	1.329	1.833	2.093
503	0.445	0.550	0.640	0.680	0.665	0.675	0.628	1.014	1.300	1.738	2.064

— Restack

heets			32 Sheets					Stacked Panels: Total Sheets			
								64	96	128	160
811	0.822	0.674	0.966	0.896	0.830	0.990	0.970	1.368	1.712	2.015	2.336
715	0.635	0.685	0.880	0.713	0.647	0.881	0.791	1.066	1.500	1.664	2.065
921	0.786	0.650	0.829	0.695	1.095	0.831	0.775	1.065	1.557	1.905	2.300
611	0.564	0.700	0.587	0.688	0.758	0.617	0.751	1.042	1.508	1.780	2.366
688	0.734	0.718	0.836	0.788	0.777	0.783	0.770	1.096	1.503	1.825	2.208
692	0.636	0.592	0.831	0.775	0.777	0.797	0.755	1.070	1.368	1.747	2.114
747	0.849	0.652	0.855	0.640	0.833	0.813	0.756	1.225	1.400	1.731	2.300
641	0.675	0.642	0.761	0.700	0.684	0.823	0.790	1.170	1.425	1.729	2.213
947	0.669	0.681	0.763	0.696	1.003	0.838	0.770	1.185	1.533	1.942	2.290

FOLDOUT FRAME

Table A-8

PANEL THICKNESS MEASUI

(Inches)

Material: Embossed Double Aluminized Mylar (Tissuglas)

Initial Stacking

Measurement Location	15 Sheets					25 Sheets				
1	0.467	0.642	0.571	0.375	0.381	0.663	0.851	0.748	0.619	0.631
2	0.352	0.300	0.301	0.380	0.251	0.446	0.490	0.521	0.640	0.496
3	0.294	0.254	0.254	0.382	0.254	0.386	0.462	0.585	0.458	0.441
4	0.451	0.545	0.582	0.495	0.377	0.646	0.816	0.835	0.632	0.494
5	0.245	0.443	0.335	0.320	0.270	0.368	0.638	0.628	0.721	0.439
6	0.356	0.388	0.239	0.263	0.240	0.397	0.561	0.589	0.579	0.383
7	0.338	0.581	0.446	0.385	0.341	0.520	0.819	0.686	0.558	0.506
8	0.281	0.332	0.278	0.335	0.242	0.417	0.492	0.446	0.485	0.394
9	0.283	0.311	0.284	0.280	0.281	0.377	0.496	0.452	0.415	0.325

Restacked

Measurement Location	15 Sheets					25 Sheets				
1	0.421	0.437	0.414	0.446	0.361	0.662	0.625	0.616	0.759	0.607
2	0.278	0.365	0.311	0.396	0.380	0.456	0.485	0.476	0.508	0.550
3	0.245	0.275	0.265	0.292	0.361	0.403	0.424	0.411	0.483	0.571
4	0.422	0.498	0.475	0.533	0.462	0.702	0.625	0.587	0.603	0.723
5	0.372	0.472	0.256	0.517	0.420	0.629	0.591	0.553	0.662	0.621
6	0.361	0.369	0.253	0.314	0.373	0.498	0.565	0.442	0.539	0.593
7	0.478	0.441	0.367	0.375	0.386	0.583	0.621	0.544	0.523	0.679
8	0.232	0.328	0.237	0.269	0.285	0.386	0.477	0.373	0.436	0.435
9	0.262	0.343	0.245	0.354	0.272	0.411	0.474	0.429	0.420	0.429

FOLDOUT FRAME

Table A-8

THICKNESS MEASUREMENTS
(Inches)

Initial Stacking

Sheets		
. 748	0. 619	0. 631
. 521	0. 640	0. 496
. 585	0. 458	0. 441
. 835	0. 632	0. 494
. 628	0. 721	0. 439
. 589	0. 579	0. 383
. 686	0. 558	0. 506
. 446	0. 485	0. 394
. 452	0. 415	0. 325

35 Sheets				
0. 802	0. 965	0. 822	0. 746	0. 791
0. 531	0. 655	0. 570	0. 597	0. 584
0. 490	0. 491	0. 627	0. 598	0. 519
0. 678	0. 954	0. 982	0. 830	0. 709
0. 475	0. 550	0. 706	0. 680	0. 628
0. 464	0. 462	0. 563	0. 541	0. 592
0. 745	0. 844	0. 869	0. 643	0. 675
0. 468	0. 570	0. 573	0. 575	0. 539
0. 516	0. 495	0. 567	0. 510	0. 506

Stacked Panels: Total Sheets			
70	105	140	175
1. 080	1. 388	1. 966	2. 403
0. 839	1. 150	1. 401	1. 730
0. 809	1. 314	1. 566	1. 784
1. 020	1. 353	1. 705	2. 128
0. 850	1. 121	1. 374	1. 648
0. 887	1. 076	1. 555	1. 815
1. 036	1. 294	1. 964	1. 706
0. 825	1. 127	1. 382	1. 850
0. 804	1. 350	1. 581	2. 330

Restacked

Sheets		
. 616	0. 759	0. 607
. 476	0. 508	0. 550
. 411	0. 483	0. 571
. 587	0. 603	0. 723
. 553	0. 662	0. 621
. 442	0. 539	0. 593
. 544	0. 523	0. 679
. 373	0. 436	0. 435
. 429	0. 420	0. 429

35 Sheets				
0. 802	0. 795	0. 876	0. 895	0. 830
0. 591	0. 594	0. 748	0. 608	0. 763
0. 538	0. 629	0. 645	0. 650	0. 666
0. 879	0. 786	0. 844	0. 828	0. 800
0. 717	0. 575	0. 760	0. 766	0. 762
0. 587	0. 616	0. 643	0. 670	0. 659
0. 750	0. 76[illegible]	0. 740	0. 651	0. 667
0. 480	0. 561	0. 498	0. 535	0. 514
0. 590	0. 665	0. 560	0. 638	0. 536

Stacked Panels: Total Sheets			
70	105	140	175
1. 250	1. 561	1. 862	2. 255
0. 845	1. 123	1. 426	1. 742
0. 929	1. 221	1. 667	1. 945
1. 009	1. 503	1. 838	2. 240
0. 854	1. 161	1. 483	1. 695
0. 927	1. 332	1. 692	1. 964
1. 178	1. 665	1. 810	2. 244
0. 846	1. 186	1. 440	1. 705
0. 974	1. 229	1. 770	1. 989

FOLDOUT FRAME

Table A-9
PANEL THICKNESS CHANG
(Settling)

DAM - Net
(40 Sheets)

Measurement Location	Table Profile	Hours 1	19	141	308
1	0.130	0.590	0.583	0.602	0.577
2	0.157	0.615	0.629	0.629	0.599
3	0.095	0.597	0.600	0.605	0.584
4	0.113	0.575	0.562	0.568	0.562
5	0.137	0.660	0.639	0.643	0.628
6	0.084	0.611	0.601	0.587	0.558
7	0.110	0.600	0.588	0.579	0.576
8	0.135	0.626	0.612	0.611	0.583
9	0.087	0.650	0.635	0.633	0.615

DAME - Tissuglas
(35 Sheets)

Table Profile	Hours 1	164	334	500
0.031	0.681	0.680	0.650	0.654
0.059	0.496	0.472	0.491	0.493
0.081	0.609	0.584	0.597	0.597
0.050	0.685	0.703	0.703	0.675
0.075	0.533	0.493	0.488	0.468
0.074	0.622	0.576	0.568	0.528
0.055	0.693	0.665	0.620	0.597
0.092	0.481	0.487	0.488	0.475
0.067	0.527	0.547	0.566	0.555

DAM - Tissuglas
(40 Sheets)

Measurement Location	Table Profile	Hours 1	171	333	668
1	0.040	0.539	0.551	0.526	0.505
2	0.046	0.475	0.452	0.426	0.403
3	0.031	0.577	0.525	0.518	0.475
4	0.040	0.569	0.536	0.523	0.468
5	0.042	0.563	0.446	0.438	0.408
6	0.041	0.550	0.481	0.480	0.455
7	0.044	0.571	0.500	0.536	0.460
8	0.057	0.541	0.472	0.470	0.440
9	0.032	0.571	0.521	0.474	0.475

DAM - Dexiglas
(32 Sheets)

Table Profile	Hours 1	193	356	525
0.038	0.713	0.663	0.806	0.836
0.047	0.660	0.598	0.590	0.590
0.038	0.882	0.843	0.720	0.728
0.025	0.801	0.711	0.714	0.755
0.021	1.005	0.776	0.719	0.702
0.040	0.817	0.779	0.737	0.731
0.029	0.968	0.797	0.663	0.685
0.029	0.921	0.898	0.895	0.909
0.059	0.787	0.710	0.722	0.740

FOLDOUT FRAME

Table A-9
, THICKNESS CHANGE WITH TIME
(Settling)

ssuglas
ets)

ours		
	334	500
0	0.650	0.654
2	0.491	0.493
4	0.597	0.597
3	0.703	0.675
3	0.488	0.468
6	0.568	0.528
5	0.620	0.597
7	0.488	0.475
7	0.566	0.555

SAME
(35 Sheets)

Table Profile	Hours			
	1	287	454	620
0.096	0.452	0.450	0.436	0.421
0.095	0.414	0.390	0.401	0.367
0.095	0.443	0.424	0.460	0.398
0.108	0.459	0.457	0.496	0.349
0.117	0.461	0.423	0.409	0.396
0.083	0.460	0.421	0.451	0.435
0.118	0.480	0.442	0.476	0.471
0.143	0.500	0.457	0.489	0.505
0.094	0.461	0.430	0.451	0.445

DAM - Foam
(23 sheets)

Table Profile	Hours			
	1	140	284	452
0.104	1.119	1.191	1.183	1.167
0.115	1.198	1.166	1.185	1.181
0.107	1.197	1.163	1.200	1.194
0.106	1.208	1.191	1.185	1.180
0.109	1.231	1.195	1.194	1.193
0.109	1.227	1.241	1.218	1.207
0.076	1.204	1.188	1.169	1.114
0.131	1.204	1.234	1.195	1.185
0.105	1.221	1.224	1.217	1.195

xiglas
ets)

ours		
	356	525
3	0.806	0.836
3	0.590	0.590
3	0.720	0.728
[illegible]	0.714	0.755
5	0.719	0.702
9	0.737	0.731
7	0.663	0.685
3	0.895	0.909
)	0.722	0.740

Superfloc
(20 sheets)

Table Profile	Hours			
	1	54	144	314
0.034	0.703	0.678	0.650	0.652
0.051	0.714	0.674	0.687	0.701
0.038	0.769	0.703	0.687	0.720
0.032	0.746	0.678	0.646	0.670
0.051	0.729	0.701	0.670	0.660
0.047	0.729	0.714	0.703	0.697
0.037	0.703	0.664	0.599	0.627
0.062	0.735	0.678	0.636	0.654
0.044	0.748	0.691	0.698	0.709

FOLDOUT FRAME

Table A-10 (page 1 of 3)
TOOLING FLATNESS

Top Plate (Mils)

-5	-4	-1	-3	-5	-5	-3	-3	-4
0	+1	+4	+3	+1	-2	+2	+4	+3
+2	+4	+4	+4	+3	0	+3	+6	+6
0	+4	+4	+6	+4	+1	+7	+7	+8
0	0	+3	+2	+2	+1	+5	+5	+9
0	+1	+1	+1	+2	-3	+5	+9	+10
+3	+6	+6	+5	+4	+2	+13	+15	+15
+3	+3	+3	+4	+4	+2	+15	+14	+13

Table A-10 (page 2 of 3)

Base Plate (Mils)

+2		+1		+1		0		+1		+1		+1		0		+1
	+2		0		+1		-1		+1		+1		0		+3	
+5		+4		+3		+1		+2		+3		+4		+4		+6
	+4		+1		+2		+3		+1		0		0		+5	
+7		+4		+1		+5		+3		+3		+3		+5		+8
	+5		+3		+4		+4		+5		+3		+2		+7	
+5		+1		-2		-1		-1		-1		-1		0		+6
	+2		0		+1		0		-3		-2		-3		+2	
-1		-2		+2		-9		-9		-6		-7		-5		0
	+5		+2		+1		+4		+1		+4		+6		+5	
+6		+5		+1		+3		+4		+6		+5		+7		+8
	+3		+2		0		+3		+2		+2		+4		+5	
-2		+2		-1		+2		+1		+3		+2		+3		+5
	+2		0		0		+1		+1		+1		+1		+2	
0		0		-4		-1		-1		0		-1		-1		0

Table A-10 (page 3 of 3)

Top Plate Deflection (Inches)

Note: Measured down from a flat reference plane.

1.450	1.447	1.455	1.453	1.451	1.452	1.450	1.446	1.445
1.449	1.448	1.453	1.459	1.454	1.453	1.451	1.445	1.445
1.451	1.450	1.450	1.458	1.462	1.460	1.457	1.449	1.447
1.441	1.446	1.447	1.448	1.452	1.452	1.450	1.444	1.443
1.437	1.436	1.437	1.440	1.449	1.447	1.451	1.450	1.446

Table A-11

FABRICATED PANEL THICKNESS SURVEY
(Material: Double Aluminized Mylar-Foam)

	0.856		0.846		0.903		0.871		0.850		0.854		0.829		0.849	
0.870		0.863		0.856		0.865		0.843		0.868		0.868		0.847		0.856
	0.859		0.858		0.868		0.867		0.855		0.856		0.864		0.864	
0.870		0.857		0.861		0.873		0.871		0.865		0.863		0.862		0.868
	0.869		0.857		0.867		0.860		0.865		0.868		0.866		0.869	
0.885		0.867		0.870		0.875		0.873		0.871		0.868		0.864		0.870
	0.871		0.877		0.882		0.862		0.869		0.870		0.856		0.866	
0.866		0.860		0.867		0.892		0.869		0.866		0.857		0.856		0.864
	0.855		0.874		0.891		0.862		0.859		0.862		0.864		0.856	
0.862		0.881		0.880		0.882		0.865		0.875		0.879		0.858		0.866
	0.857		0.859		0.871		0.863		0.862		0.852		0.847		0.850	
0.845		0.850		0.855		0.847		0.823		0.834		0.826		0.834		0.847
	0.844		0.821		0.829		0.872		0.831		0.887		0.814		0.827	

Table A-12

FABRICATED PANEL THICKNESS SURVEY
(Material: 11 Sheets of Superfloc)

	0.382		0.380		0.371		0.381		0.392		0.397		0.364		0.385	
0.364		0.374		0.371		0.374		0.366		0.373		0.382		0.387		0.371
	0.377		0.369		0.365		0.367		0.371		0.385		0.384		0.375	
0.358		0.384		0.379		0.385		0.380		0.365		0.379		0.392		0.362
	0.369		0.380		0.376		0.385		0.386		0.389		0.389		0.382	
0.339		0.362		0.365		0.377		0.382		0.385		0.364		0.382		0.354
	0.346		0.362		0.376		0.388		0.384		0.371		0.365		0.372	
0.349		0.366		0.365		0.390		0.379		0.379		0.369		0.379		0.352
	0.373		0.375		0.382		0.388		0.382		0.380		0.394		0.372	
0.391		0.390		0.374		0.396		0.384		0.394		0.394		0.406		0.377
	0.385		0.387		0.389		0.388		0.385		0.381		0.386		0.368	
0.369		0.377		0.376		0.398		0.383		0.378		0.385		0.402		0.371
	0.381		0.403		0.381		0.405		0.394		0.394		0.394		0.396	

Table A-13

FABRICATED PANEL THICKNESS
(MATERIAL: 21 Pair of Double Aluminized Mylar and Net Spacer)

	0.274		0.271		0.275		0.269		0.272		0.272		0.269		0.272	
0.274		0.270		0.273		0.265		0.277		0.271		0.275		0.269		0.268
	0.267		0.267		0.270		0.277		0.271		0.268		0.269		0.273	
0.276		0.271		0.265		0.272		0.279		0.274		0.276		0.274		0.273
	0.27[illegible]		0.273		0.275		0.277		0.275		0.277		0.270		0.272	
0.28[illegible]		0.276		0.275		0.284		0.280		0.283		0.282		0.287		0.285
	0.277		0.287		0.288		0.288		0.284		0.287		0.279		0.291	
0.266		0.265		0.277		0.274		0.284		0.292		0.279		0.273		0.281
	0.279		0.286		0.290		0.283		0.276		0.271		0.274		0.284	
0.278		0.291		0.279		0.285		0.293		0.291		0.280		0.273		0.281
	0.276		0.283		0.279		0.272		0.275		0.284		0.280		0.278	
0.273		0.279		0.272		0.279		0.289		0.279		[illegible]79		0.275		0.285
	0.305		0.265		0.286		0.318		0.294		0.294		0.312		0.274	

Table A-14

FABRICATLD PANEL THICKNESS
(MATERIAL: 19 Pair of Embossed Double Aluminized Mylar and Tissuglas Spacer)

	0.291		0.290		0.358		0.419		0.333		0.336		0.340		0.292	
0 253		0.317		0.296		0.282		0.284		0.358		0.298		0.318		0.320
	0.232		0.295		0.353		0.357		0.306		0.315		0.305		0.304	
0.251		0.301		0.289		0.311		0.318		0.349		0.297		0.315		0.259
	0.295		0.305		0.348		0.371		0.368		0.348		0.332		0.320	
0.300		0.279		0.279		0.319		0.331		0.315		0.295		0.312		0.33.
	0.268		0 263		0.389		0.325		0.304		0.295		0.270		0.286	
0.261		0.254		0.258		0.318		0.295		0.314		0.278		0.284		0.260
	0.250		0.260		0.293		0.303		0.286		0.277		0.289		0.278	
0.252		0.312		0.301		0.320		0.286		0.320		0.303		0.310		0.284
	0.326		0.362		0.364		0.359		0.357		0.349		0.333		0.321	
0.377		0.342		0.449		0.481		0.462		0.529		0.404		0.398		0.354
	0.519		0.530		0.620		0.609		0.624		0.522		0.564		0.465	

Table A-15

FABRICATED PANEL THICKNESS
(MATERIAL: 17 Pair of Double Aluminized Mylar and Dexiglas Spacer)

	0.270		0.264		0.272		0.298		0.284		0.288		0.297		0.294	
0.271		0.269		0.279		0.268		0.282		0.285		0.294		0.307		0.322
	0.265		0.252		0.273		0.268		0.263		0.269		0.272		0.282	
0.256		0.265		0.266		0.279		0.278		0.281		0.274		0.295		0.277
	0.271		0.271		0.272		0.288		0.288		0.268		0.288		0.292	
0.260		0.270		0.265		0.288		0.285		0.284		0.276		0.276		0.269
	0.271		0.270		0.277		0.285		0.291		0.275		0.282		0.275	
0.256		0.273		0.275		0.292		0.286		0.292		0.280		0.280		0.270
	0.282		0.287		0.297		0.284		0.313		0.292		0.318		0.295	
0.266		0.279		0.279		0.290		0.288		0.300		0.275		0.301		0.270
	0.262		0.270		0.250		0.255		0.260		0.266		0.266		0.272	
0.269		0.285		0.266		0.277		0.276		0.273		0.272		0.301		0.275
	0.265		0.290		0.266		0.297		0.295		0.299		0.283		0.317	

Table A-16

FABRICATED PANEL THICKNESS SURVEY
(MATERIAL: 16 Pair of Double Aluminized Mylar and Tissuglas Spacer)

	0.195		0.192		0.178		0.202		0.178		0.190		0.184		0.183	
0.203		0.190		0.183		0.180		0.177		0.197		0.180		0.199		0.203
	0.211		0.214		0.209		0.229		0.216		0.205		0.203		0.182	
0.213		0.194		0.202		0.230		0.208		0.227		0.210		0.221		0.219
	0.230		0.236		0.223		0.240		0.243		0.235		0.246		0.235	
0.213		0.209		0.225		0.218		0.216		0.233		0.209		0.214		0.209
	0.211		0.210		0.203		0.219		0.216		0.226		0.219		0.224	
0.197		0.194		0.201		0.192		0.203		0.211		0.207		0.215		0.212
	0.194		0.199		0.196		0.212		0.202		0.199		0.202		0.207	
0.195		0.178		0.196		0.197		0.189		0.206		0.211		0.211		0.196
	0.203		0.212		0.281		0.213		0.206		0.211		0.211		0.196	
0.231		0.225		0.227		0.252		0.231		0.251		0.191		0.204		0.211
	0.261		0.276		0.232		0.286		0.267		0.250		0.247		0.232	

Table A-17

FABRICATED PANEL THICKNESS
(MATERIAL: 54 Sheets of Embossed Single Aluminized Mylar)

	0.440		0.395		0.349		0.406		0.412		0.373		0.345		0.367	
0.368		0.395		0.393		0.415		0.347		0.396		0.353		0.424		0.364
	0.349		0.326		0.302		0.344		0.352		0.332		0.309		0.306	
0.321		0.310		0.305		0.297		0.303		0.302		0.307		0.319		0.333
	0.300		0.292		0.282		0.300		0.300		0.293		0.316		0.306	
0.314		0.305		0.302		0.305		0.335		0.338		0.337		0.318		0.325
	0.314		0.310		[illegible]		0.348		0.344		0.332		0.321		0.314	
0.332		0.313		0.314		0.340		0.341		0.345		0.349		0.324		0.329
	0.342		0.326		0.341		0.427		0.340		0.415		0.369		0.389	
0.385		0.356		0.366		0.389		0.375		0.443		0.396		0.397		0.365
	0.352		0.452		0.391		0.454		0.414		0.497		0.462		0.444	
0.395		0.519		0.470		0.486		0.392		0.438		0.399		0.536		0.500
	0.531		0.352		0.398		0.529		0.508		0.554		0.616		0.594	

Table A-18

PANEL THICKNESS CHANGE CAUSED BY PUNCHING OPERATION (mils)

(MATERIAL: Double-Aluminized Mylar - Foam)

14	15	13	22	49	36	-5	12	20
-1	17	5	20	16	9	27	8	2
1	17	-12	-8	20	12	1	9	5
14	11	15	16	15	12	19	10	6
16	12	14	3	-2	13	23	17	4

(Superfloc)

5	29	-5	51	20	24	25	22	-16
21	26	18	15	8	3	31	50	43
14	17	17	27	12	15	19	5	40
9	36	5	6	10	10	-8	-9	6
3	16	-2	-58	21	-8	-27	-76	6

(Double-Aluminized Mylar - Net)

4	4	-3	-3	0	-27	-10	1	-4
-11	6	11	-18	4	-10	-12	8	-5
3	-2	6	-3	7	-3	-8	-7	-4
1	-3	9	-4	0	-11	8	8	-3
6	-2	-11	10	-9	0	-4	3	1

(Embossed Double-Aluminized Mylar - Tissuglas)

4	-12	-3	-8	-22	-2	-27	-45	-28
8	-17	-7	3	-1	0	-3	0	-40
0	-8	-30	10	16	-4	-6	0	2
-10	-2	-49	-19	-1	1	11	30	-4
-6	-16	3	4	-39	-53	0	6	-6

(Embossed Single Aluminized Mylar)

-49	-4	-2	12	-26	15	-46	-68	-27
-45	-2	-16	-12	-4	16	-11	11	-13
-36	-28	-12	-8	-47	[illegible]	-43	-11	-21
-62	-32	-90	22	-8	10	24	-22	12
-7	-14	38	-17	60	-50	11	-4	-39

(Double-Aluminized Mylar - Tissuglas)

-16	-16	23	-46	-13	-57	-2	-42	-23
-53	-2	2	-12	-20	-35	-2	2	-37
-12	-27	-25	16	-38	-8	4	-10	-43
1	-36	-27	-7	-6	1	2	1	-48
-44	-36	-1	-9	-37	-38	-40	-29	-34

(Double-Aluminized Mylar - Dexiglas)

5	-5	-22	10	4	4	-1	9	6
9	-7	-8	9	3	24	3	7	1
6	4	-13	5	12	3	16	13	5
-5	-7	-6	-9	-6	2	2	14	7
10	9	-8	10	9	21	10	10	5

Appendix B
PROCEDURAL STEPS FOR DETERMINING MNV INSULATION REQUIREMENTS

Table 3-12 listed the procedural steps involved in determining the MNV insulation requirements. The following paragraphs delineate a numerical example of this procedure using Superfloc.

Step 1: Choose a rejection rate.
The calculation will be performed at a fabricated panel acceptance rate of 75% (25% rejection).

Step 2: Select a layer density range of interest (with settling).
From Table 2-4 it can be found that Superfloc panels, when constructed with 10 to 20 sheets per panel, have a layer density of 26.5 to 27.8 sheets per inch or less 75% of the time. Using the settling data (Table 2-12), it appears that Superfloc panels settle at least 10%. To compensate for this the layer density range of interest is increased 10% to 29.2 to 30.6.

Step 3: Determine the range of optimum N.
Table 3-4 gives the optimum number of layers of Superfloc required as a function of layer density and total mission heat short. This is used to determine that the optimum number of layers required is between 24 and 27 for an applied layer density of 29.2 to 30.6 sheets per inch with an assumed total mission heat short of 1.5×10^6 Btu.

Step 4: Pick an N within the range of optimum N.
Assume an N of 27.

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Step 5: Determine the number of panels, P.

This is not a quantitative determination. It is desirable from a thermal standpoint to have several panels as this tends to reduce insulation degradation at insulation joints. From a fabrication standpoint it becomes difficult to construct panels much less than 1/4-in. thickness. Therefore select P = 3.

Step 6: Divide $N/P = N_P$ (number of sheets in a panel).

With 27 sheets total (step 4) and 3 panels (step 5), the number of sheets in a panel is 9.

Step 7: Determine the layer density for N_P, LD_P.

Returning to Table 2-4, the density study data for Superfloc, the closest available data is for ten-sheet panels which have a layer density of 26.5. Adding 10% for settling yields panels which will have a layer density of 29.2 or less at least 75% of the time.

Step 8: Determine the optimum N, N_{opt}, for LD_P.

Double interpolation within Table 3-4 shows that this layer density corresponds to an optimum number of layers of 23.6 at a total mission heat short of 1.5×10^6 Btu.

Step 9: Does N_{opt} equal the N picked in step 4?

The optimum number of layers resulting at the end of step 8 (23.6) is substantially different from the value assumed in step 4 (27). Thus it is necessary to repeat steps 4 through 8 until agreement is obtained. The general procedure is to use the result of step 8 as an input to step 4 and then repeat steps 5 through 8. Using 24 as an input to step 4 and assuming three panels, there will be eight sheets per panel. Using Table 2-4 data at the closest available study panel (10 sheets), the layer density is 26.5. Adding 10% for settling and then utilizing Table 3-4, the optimum number of layers is 23.6 — in good agreement with the assumed value.

The procedure is identical at other rejection rates or with other insulations. However, certain drawbacks are inherent not so much in the procedure but in the limited amount of density study data. In the above example, the number of sheets in a panel fell outside the range of Table 2-4 data. The data could be extrapolated; however, the general rule used with the results of this report was: If the value lies outside the range for the table then use the closest available data but if the value lies within the range of the table, then interpolate. Another problem encountered was that the statistical results of the measurement study (Tables 2-4 through 2-10) often showed a higher layer density with a small number of sheets than with a large number of sheets. In reality this is not the case. This apparent error is a result of the limitations of the applied statistical data reduction approach when used with thin panels having considerable variability. The foam and Superfloc systems, having the lowest variability, show the least perturbation due to this problem.

The procedure delineated above for determining the optimum MNV insulation was used with all systems. Data points for each system were calculated at various rejection rates. Once the optimum number of sheets was determined the weight of the system was calculated from the area of the vehicle and the weight per square foot per sheet of insulation. This procedure is valid for determining the optimum amount of insulation on either sidewall or dome areas as discussed in Subsection 3.4.3. The procedure for dual optimization (Subsection 3.3.4) is similar but more complex.

Appendix C
NOTES ON FABRICABILITY OF INSULATION MATERIALS

A compilation of informal notes on fabricability of the candidate insulation systems is presented below. The notes include comments on specific problems and, in some cases, suggested solutions. Comments in regard to fabrication in general are also included.

Double Aluminized Mylar (DAM)

DAM material has damaged edges. The amount of damage varies throughout a roll. Approximately 1 in. had to be trimmed from each edge for this study. Pinholes were noted in the material. Some holes had sharp edges — a potential tear point.

Superfloc

1. Current material had many defective areas. Flocking was not uniform. In some areas the floc points were larger than normal, in other areas the flocking was missing. Both length and width edges required trimming. Length edge defects were probably due to base material.
2. Cutting of the Superfloc sheets required special care. The material tended to tear at points where a knife blade crossed a floc point. The material could be cut using a sharp X-acto knife held at a shallow angle.
3. Individual sheet packaging increased fabrication time.
4. The 12-foot maximum length was considered the most serious drawback.
5. Top and bottom sheet reinforcement was [illegible] to be insufficient when panel had to be handled at attachment [illegible].
6. Flocking sheds and could result in chaff in an insulation blanket.
7. This material has less tendency to wrinkle than Tissuglas, Dexiglas, or nylon net.

DAM Foam

1. One man was allergic to foam dust (sneezing, itching, etc.). Three other people who worked closely with the system were not affected.
2. Foam chaff could be in a completed panel.
3. Individual sheet packaging increases fabrication time.
4. Special attention is required to cut a panel. An X-acto knife with a 3-in. blade produces a wavy cut. A straight cut can be achieved with a blade tip guide. However, there is a tendency to tear center material even when the blade is held at shallow angles. A powered cut off tool would probably be better.

DAM/Nylon Net

1. Standard width for the net is 72 in. If this width is used, procurement documents should clearly specify that no folding is permitted. The suppliers standard shipping procedure folds the 72-in. width.
2. This system is somewhat similar to Superfloc with regard to cutting. There is tendency to tear at the points where the blade crosses the net. Again a sharp X-acto knife held at a shallow angle gave clean straight cuts.
3. The net should be precut to expedite fabrication.
4. The cut edges on the net tend to cling to gloves and to the DAM distorting the layup. This problem was circumvented in this study by cutting the net width slightly less than the DAM width. Pairs could then be handled without touching a cut net edge.

SAME

1. Both of the embossed materials showed a pronounced stretching effect. Sheets were rippled rather than flat. This distortion is carried through the fabrication and results in panels with widely varying thicknesses.
2. The embossing height is substantially lower on material near the end of the roll. Therefore layup thickness varies throughout the roll.
3. There are no cutting problems with this system.

DAM/Tissuglas

1. Discoloration was noted on the edges of the Tissuglas rolls. A question exists on the stability of the binder.
2. The Tissuglas, while fragile, can be handled rather easily without damage. Material can be fed from rollers to supporting DAM sheet easily.

3. Tissuglas sheets tend to wrinkle on layup. Wrinkles can be removed with careful adjusting.

4. The smaller width, 3.5 ft, is not a serious handling problem. Since the edges of the Tissuglas and the DAM are straight, there was no material runout as materials are pulled from the rolls.

DAM/Dexiglas

1. Dexiglas is extremely fragile. Feeding the material from the roll to the supporting sheet requires great care. The material could not be pulled with the fingers at all. In this study, material was first separated from the roll using a thin dull blade and then fed to the DAM sheet supported by workers arms. Special pullout tooling would be required for production.

2. The material tends to fold, crease, and wrinkle; adjustment is not feasible.

DAME/Tissuglas

1. See notes on SAME and DAM/Tissuglas systems.

General Notes

1. Panel sheets should be cut slightly oversize and each sheet taped in place on the layup tool at the outer edges. Care should be taken to assure that there is no tension on the anchored sheet.

2. Adding or removing the top-plate is a delicate operation. Any rapid movement creates air currents which seriously disrupt the panel.

3. Care must be taken in tooling design to permit access to all attachment points.

4. Small bits of foreign material and chaff can be removed from DAM by holding a piece of Scotch 850 tape near the offending material – static charge will attract the offender without need for contact.